Navigating the modular shift:

Insights from real estate developers in the Netherlands

Thijs Müller

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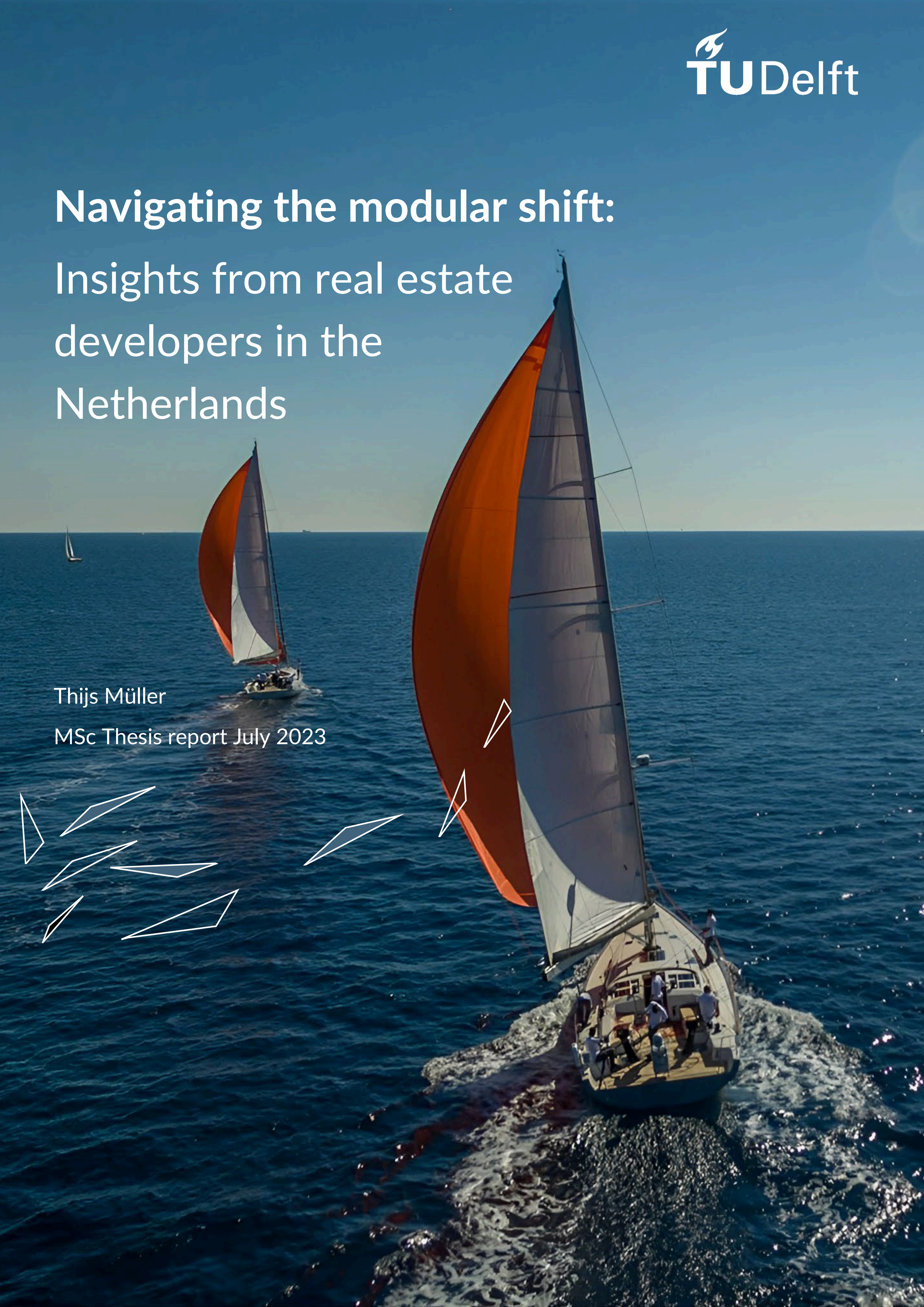

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THESIS REPORT

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Navigating the modular shift: Insights from real estate developers in the Netherlands

MASTERS THESIS REPORT

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Preface

Thijs Müller
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In my childhood, cityscapes filled with awe-inspiring buildings stirred my imagination, sparking a lifelong passion for Architecture, Engineering, and Construction industry. As I delved into this world, I recognized the industry's traditionally conservative nature, marked by a slow pace of innovation. Yet, throughout my master’s studies, I unearthed promising trends that infuse this field with innovation and appeal, despite inherent risks and uncertainties.

Observing the trend of 'logolization' in our built environment, I appreciate its potential to enhance efficiency, productivity, and sustainability. However, I question the trade-off: a uniformity that risks eroding the diverse and unique identities of individual buildings and the vibrant cityscapes they form. I firmly believe in the power of our built environment to shape human interactions, a belief underscored by contrasting the welcoming squares of Copenhagen, Denmark, with the isolating skyscrapers in densely populated cities. Yet, we must reconcile this with the unceasing march of progress – a powerful force that, while we may resist, will persist, driving us forward.

This sentiment is eloquently echoed in Steven Pinker's "Enlightenment Now: The Case for Reason, Science, Humanism, and Progress," where he posits progress as integral to our evolution as individuals and society. To ignore progress is to deny our potential for advancement—an insight that resonates profoundly as I explore construction industrialization and the evolving role of real estate developers.

During my journey into the construction industry, I encountered conservatism and fragmentation, but instead of frustration, these challenges ignited my motivation. They spurred me to question and innovate. Can't we do better? This rhetorical question forms the driving force behind this thesis.

By adopting innovative techniques such as Modular Construction, we can boost efficiency and sustainability while fostering designs that enhance, not homogenize, our cityscapes. Suddenly, ideas once deemed unfeasible become possible, encompassing not only technical feasibility but also societal and economic viability. The sustainable Hotel Jakarta stands as a testament to this concept. Through industrialization, the seemingly impossible becomes attainable.

This dissertation is my humble contribution to this ongoing discourse. My hope is that it not only inspires, but also demonstrates the inevitability of change and progress in our built environment.

Hotel Jakarta in Amsterdam (seARCH), built with 186 wooden modules from Ursum, showcases the financial feasibility of constructing a fully wooden hotel. This sustainable approach enhances the guest experience with a characteristic design and highlights the potential of modern construction techniques. Retrieved from https://www.search.nl

“Organizations which design systems … are constrained to produce designs which are copies of the communication structures of these organizations.”

Conways’s Law (1968)

Abstract

The productivity and sustainability issues in the construction industry are leading to the consideration of systemic innovations such as modular construction. The industry's complex and fragmented structure resulting in an established practice of aligning knowledge with specific tasks impedes the adoption of such innovations. This phenomenon, known as the 'mirroring trap,' obstructs businesses from identifying opportunities for adjusting their limits or restructuring their sector. Recent studies primarily examine integration strategies that facilitate the breakout from this trap. However, these studies predominantly emphasize the involvement of the main contractor and architect, while there is a noticeable lack of research on the role of real estate developers in this context. This lack of attention to real estate developers is unexpected, given their significant role in housing development within the Netherlands. The research aims to investigate how real estate developers integrate modular construction in their business. The research methodology employs a balanced approach as an iterative process between literature and empirical research. Six organisation structures were analysed with eleven expert interviews– Decentralized modular cluster; Collaborative modular clusters; Virtual project-based companies; Spin-off factory; Core-periphery platform; Integrated hierarchical firms. This thesis presents three approaches for integrating modular construction; 1) Project-based strategies incorporate modular construction via supply chain integration or through formal supplier networks, 2) Hybrid-based strategies blend industrialized construction techniques with a flexible, project-centric organizational structure via Integrated Project Delivery (IPD) and 3) product-based strategies concentrate on strategically breaking mirrors to achieve integrated organizational structures. Integration mechanisms, drivers, and challenges are identified for each. The strategies show that real estate developers play a crucial role in the integration of modular construction, and understanding the wide spectrum of strategies and tailoring them to specific contexts of the company can lead to more successful integration of modular construction. The thesis concludes with a discourse on how pinpointing and detailing integration strategies for strategic *partial mirroring* or *breaking the mirror* enhance the comprehension of integration in modular construction. It highlights the industrialization of construction development as a recurring theme and includes the current business structure's constraints. Moreover, it provides seven pragmatic suggestions for property developers to ponder over when assimilating modular construction.

Keywords: Modular Construction; Integration Strategies; Real Estate Developers; Mirroring hypothesis; Organizational Structures

Abstract (NL)

De productiviteits- en duurzaamheidsproblemen in de bouwindustrie leiden tot het verkennen van systemische innovaties zoals modulaire bouw. De complexe en gefragmenteerde structuur van de industrie, die resulteert in een gevestigde praktijk van het afstemmen van kennis op specifieke taken, belemmert de adoptie van dergelijke innovaties. Dit fenomeen, bekend als de 'mirroring trap', belemmert bedrijven om kansen te identificeren om hun grenzen aan te passen of hun sector te herstructureren. Uit recente studies blijkt hoe integratiestrategieën individuele projecten of organisaties in staat stellen om aan deze val te ontsnappen, waarbij vooral wordt gefocust op de rol van de hoofdaannemer en de architect, maar veel minder bekend is over de rol van de vastgoedontwikkelaar in deze context. Dit is verrassend gezien hun belangrijke rol bij woningontwikkeling in Nederland. Het onderzoek heeft als doel te onderzoeken hoe vastgoedontwikkelaars modulaire bouw integreren in hun bedrijfsvoering. De onderzoeksmethodologie hanteert een gebalanceerde aanpak als een iteratief proces tussen literatuur en empirisch onderzoek. Zes organisatiestructuren zijn geanalyseerd met elf expertinterviews: gedecentraliseerd modulair cluster; samenwerkende modulaire clusters; virtuele project gebaseerde bedrijven; spin-off fabriek; kern-periferieplatform; geïntegreerde hiërarchische bedrijven. Deze scriptie presenteert drie benaderingen voor het integreren van modulaire bouw: 1) Op project gebaseerde strategieën omvatten modulaire bouw via supply chain-integratie of via formele leveranciersnetwerken, 2) Gemengde strategieën combineren geïndustrialiseerde bouwtechnieken met een flexibele, projectgerichte organisatiestructuur via Integrated project Delivery (IPD) en 3) product gebaseerde strategieën concentreren zich op het strategisch doorbreken van spiegels om geïntegreerde organisatiestructuren te bereiken. Integratiemechanismen, drijfveren en uitdagingen zijn voor elk van deze benaderingen geïdentificeerd. De strategieën tonen aan dat vastgoedontwikkelaars een cruciale rol spelen in de integratie van modulaire bouw, en dat het begrijpen van het brede spectrum aan strategieën en het op maat maken ervan voor de specifieke context van het bedrijf kan leiden tot een succesvollere integratie van modulaire bouw. De scriptie concludeert met een discussie over hoe het nauwkeurig bepalen van integratiestrategieën voor strategisch gedeeltelijk spiegelen of het doorbreken van de spiegel het begrip van integratie in modulaire bouw verbetert. Het benadrukt de industrialisatie van bouwontwikkeling als een terugkerend thema en omvat de beperkingen van de huidige bedrijfsstructuur. Bovendien worden zeven pragmatische aanbevelingen geboden voor vastgoedontwikkelaars om te overwegen bij de integratie van modulaire bouw.

Keywords: Modular Construction; Integration Strategies; Real Estate Developers; Mirroring hypothesis; Organizational Structures

Table of Contents

List of figures

List of Tables

1

General introduction and thesis foundation

General Introduction

> *"In 2008, Apple announced the release of the App Store platform with the first 500 apps available. The combination of the new iPhone with the App Store platform was one of the key factors that led to the disruption of the mobile phone industry, paving the way for Apple to become a dominant player in the smartphone market for decades to come. The App Store represented a new platform-based business model that enabled tremendous value capture from the new technology of the iPhone. Business model scholars have understood this for some time. The development of innovative technology alone will not transform or disrupt an industry. Instead, disruption occurs when an innovative technology is paired with the development of a new and transformative business model."*
>
> *(Hall, Lessing, and Whyte, 2022, p. 123)*

Modular construction

Advancing Productivity and Sustainability

The global landscape of the construction industry is faced with an urgent challenge of enhancing productivity and sustainability. This sector, integral to both economic growth and citizen wellbeing, has been long criticized for its inefficiencies and fragmented nature (Hasan et al., 2018; McKinsey Global Institute, 2017). Despite contributing approximately 9% to the Dutch GDP and generating over €70 billion (Bouwend Nederland, 2021), the construction sector's productivity growth lags behind other industries (Larsson et al., 2014; Changali et al., 2015). Studies by Horman and Kenley (2005), Mossman (2009), Larsson et al. (2014), and others have consistently shown that conventional on-site construction projects waste significant resources such as time and materials, which negatively affects productivity. Like other industries, it has been found that addressing waste and improving productivity can be achieved through the continuous improvement of industrialized processes, as emphasized by Winch (2003). Therefore, the adoption of innovative solutions becomes increasingly crucial (Bertram et al., 2019). The traditional business model in the construction sector has numerous shortcomings, which contributes significantly to the existing *productivity gap* (Hassan, 2018; Barbosa, Woetzel, and Mischke, 2017). McKinsey and Company (Changali, et al., 2015) argued that Industrialized Construction has the potential to enhance efficiency and productivity in the construction sector, approaching the practices in the manufacturing sector (see Figure 1).

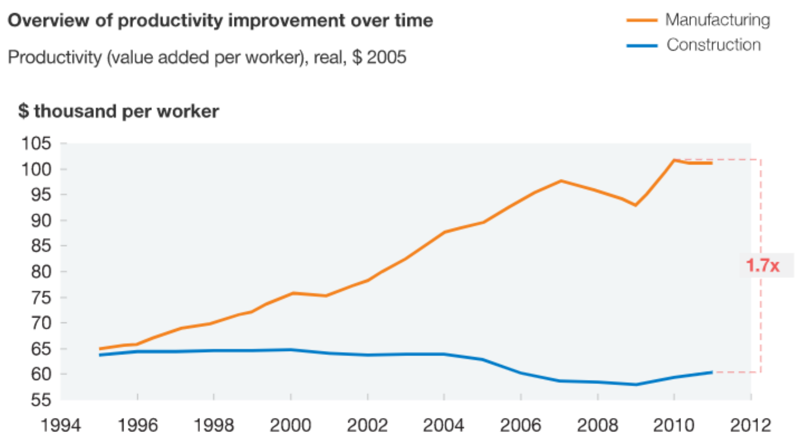

Figure 1: Overview of productivity improvement over time (Belgium, France, Germany, Italy, Spain, United Kingdom, United States); World Input-Output Database from McKinsey and Company (adapted from Changali, Mohammad, and van Nieuwl, 2015)

In addition to this productivity gap, the construction sector represents a significant proportion of both global energy consumption and CO_2 emissions, respectively 36% and 39% in 2018 according to the United Nations Environment Programme (2021). The sector is also responsible for about 40% of annual global material resource usage and similarly generates 40% of total annual waste (Purchase, 2022). These figures underscore the need for the construction sector to contribute to the Paris Agreement climate objectives through the development and implementation of more sustainable building materials, efficient construction methods, and closed-loop material cycles (UN, 2016).

Industrialization of the Construction Sector

A possible solution for sustainability and productivity problems is the industrialization of the construction sector. Industrialized Construction, a term that describes the shift toward new concepts and strategies within the sector, could offer opportunities for new business models (Lessing et al., 2015). This goes beyond merely moving production to a controlled factory environment; It involves taking a comprehensive approach that builds long-lasting relationships, incorporates efficient supply chain management and logistics, devises innovative technical systems, captures knowledge for ongoing improvement, strategically plans and oversees processes, and enhances comprehension of customer and market demands. (Lessing et al., 2015; Masood et al., 2022; Hall, Lessing, and Whyte, 2022).

Modular Construction, a specific form of Off-Site Construction, plays a significant role in this change. Modular construction can manufacture up to 90% of a complete building in a factory (Pan and Hon, 2020). It provides benefits such as shorter construction time, lower labour costs, quicker learning curves, reduced project life cycle costs and energy (e.g. lu and korman, 2010); Bertram, 2019; Pan and Hon,2020). Off-site manufacturing of building components in controlled factories offers benefits such as precision, quality control, and standardized processes. This enables the use of innovative and biobased materials such as *mass timber*, which effectively store CO_2 (van der Lugt, 2020).

Industrialized Construction in the Netherlands

The Dutch housing sector is experiencing considerable strain, largely precipitated by a combination of high demand and a scarcity of affordable homes, which restricts a portion of society from home ownership. The prediction for 2022 indicates a housing deficit of approximately 340,000 units. This dearth has been a contributing factor to the significant surge in house prices within the Netherlands, placing it among the highest in the European Union in the past year (Rauh and Sturm, 2023). Concurrently, the sector faces multiple operational challenges including escalating raw material costs, labour shortages, and an increasingly critical environmental issue: the nitrogen emissions crisis.

This nitrogen crisis, engendered by construction activities' nitrogen emissions from the utilization of diesel machinery and building materials, presents significant environmental implications. The Netherlands has been compelled to enact stringent measures to control these emissions, resulting in added restrictions and subsequent delays within the construction industry. Therefore, while the sector grapples with the housing shortage, it is simultaneously confronted with the task of navigating the environmental implications of nitrogen emissions, necessitating a instable balance between sustainability and housing demand.

In response to these converging challenges, the Dutch government has resolved to accelerate housing construction, targeting 100,000 units annually (BZK, 2022a). The National Housing and Construction Agenda (Nationale Woon- en bouwagenda) endorses a greater incorporation of innovative practices in residential construction to expedite production (BZKb). Additionally, an explicit emphasis is placed on the industrialization of housing construction through various government initiatives. Correspondingly, several construction firms are observed to be investing in both large-scale and small-scale industrial construction solutions.

Consequently, the potential industrial production capacity of Dutch builders is projected to increase to approximately 30,000 to 40,000 homes per year by 2025 (Sturm and Rauh, 2022). This substantial expansion underscores the pivotal role of the industrial construction sector in fulfilling governmental objectives. Moreover, the industrialized construction approach, noted for its efficiency and potential to reduce emissions, presents as an indispensable solution to concurrently address both the housing and nitrogen crises in the Netherlands (BZK, 2022; Sturm and Rauh, 2022).

The real estate developer plays a crucial role in the industrialization of the construction sector in the Netherlands. The production of new housing in the Netherlands is dominated by project developers, as shown in Figure 2 'builders for the market.' This includes project developers, real estate agents, contractors who build at their own risk (CBS, 2023). However, the industrial construction market in the Netherlands is still relatively small, representing only about 14% of the sector. This share lags other industrialized countries such as Sweden (approximately: 80%) and Japan, where industrial construction is the norm (Sturm and Rauh, 2022). This indicates potential for growth and optimization. To understand the limited integration of Modular Construction in the Netherlands, it is important to consider the perspective of developers who has the position to decide the construction method. As also noted by McKinsey and Company (2019, p37): "Real-estate developers are a natural catalyst for scaling modular construction, as they can determine how their projects are realized and by whom".

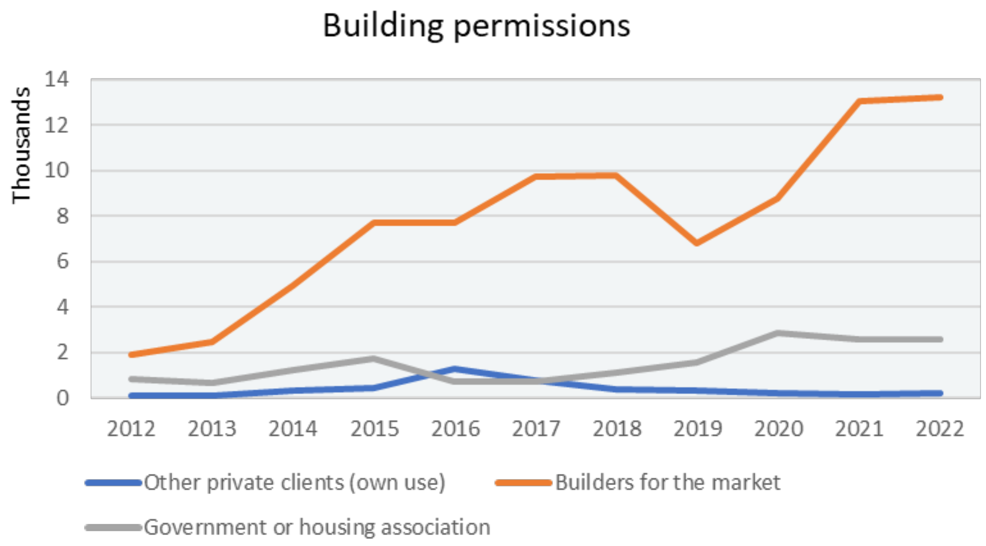

Figure 2: Overview of Building permissions for new dwellings by developer type in the Randstad of the Netherlands (Randstad = Amsterdam, Rotterdam, Den Haag and Utrecht) ; CBS (2023).

Fragmentation in the Construction Industry: The Mirror hypothesis

Innovation, despite an array of promising ideas and methods, continues to pose a significant challenge in the construction sector (Allmon et al., 2000; Blayse and Manley 2004; Sheffer, 2011). Progress is slow and typically confined within limited segments of the industry. The unique structure of the construction sector significantly contributes to this problem, as it is exceptionally fragmented (Sheffer, 2011). This fragmentation manifests at multiple levels: Horizontally, integration entails working together and coordinating activities within a particular project phase. Vertically, integration involves connecting different project phases, while longitudinally, it extends across multiple projects to ensure cohesive and seamless operations (Sheffer, 2011). The consequence is an industry dominated by a multitude of highly specialized small and micro-enterprises (Chen, Hall, Adey and Haas, 2020).

The fragmentation issue stems from the real estate market, which possesses unique characteristics that distinguish it from other markets. Real estate, both as an investment asset and as a market, exhibits distinct qualities that contribute to its fragmented nature (DiPasquale and Wheaton, 1996). The real estate market is characterized as complex, expensive (Goodman and Thibodeau, 1998), region based, subject to substantial demand fluctuations (Maisel, 1963), and typical economic real estate cycles (Hall and Soskice, 2001; Taylor and Levitt, 2004a).

Sheffer (2011) explored how this fragmented structure of the construction sector impedes innovation as visualised in Figure 3. When classifying innovations by type, the presence of vertical fragmentation, liability concerns, and demand fluctuations creates additional complexities. Systematic or integral innovations, such as modular construction, which involve changes across multiple concepts or practices, face a significantly lower adoption rate—three times less likely—compared to local innovations that operate within the existing context, like a new type of insulation (Katila, Levitt and Sheffer, 2018).

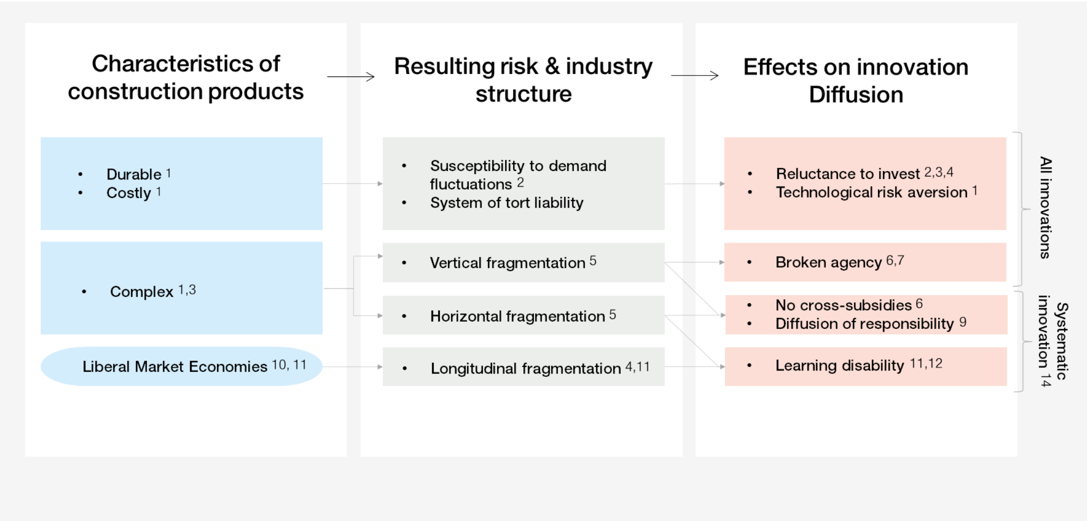

Figure 3: Structural barriers to innovation in construction (Sheffer 2011). [1]Nam and Tatum (1988); [2]Maisel (1963); [3]Gann (1996); [4]Reichstein et al. (2005); [5]Fergusson (1993); [6]Henisz et al. (2012); 7Martishaw and Sathaye (2006); [8]Tatum (1986); [9]Darley and Latane (1968); [10]Hall and Soskice (2001); [11]Taylor and Levitt (2004); [12]Dubois and Gadde (2002a); [13]Stinchcombe (1959); [14] Sheffer (2011).

Addressing fragmentation through horizontal and vertical integration of project stakeholders during project execution is essential to promote the adoption of systemic innovations (Sheffer, 2011). However, the construction sector faces a significant challenge in bridging tasks and concepts across different firms (Colfer and Baldwin, 2016; Hall, 2018).

Colfer and Baldwin (2016) identified the so-called *mirroring hypothesis*. In construction projects, coordinating complex tasks requires firms to manage their limited resources effectively. Colfer and Baldwin (2016) explained that mirroring technical dependencies and organizational structures can provide advantages in this regard (Thompson, 1967 as cited in Colfer and Baldwin, 2016). To reduce the overall complexity of the work, it is allocated into modules that can be processed independently, according to the principle of information hiding (Baldwin and Clark, 2000). Hall, Whyte and Lessing (2020) argue that the construction industry has become caught in a *mirroring* *trap* due to the institutionalization of norms, standards, and regulations over time. The mirroring trap occurs when specialized firms and their employees deeply internalize knowledge related to design, engineering, and construction, leading to a situation where it becomes difficult to break away from established behaviours and practices (Hall, et al. 2020). In essence, knowledge becomes tightly intertwined with task dependencies, resulting in a *strict mirroring* effect. Consequently, this strict mirroring hinders the ability to introduce innovative systemic changes at the project level, as it reinforces the prevailing standard system architecture (Taylor and Levitt 2004; Baldwin and Clark, 2000; Hall et al., 2020)

Staying trapped in this mirroring cycle within the construction industry presents a challenge for firms and project teams to embrace systemic innovations that have the potential to bring global benefits. Such innovations may not align with the current industry structure, project organization, and knowledge boundaries (Hall et al., 2020). This suggests a potential resistance or reluctance to embrace new approaches that deviate from established practices (Baldwin and Clark, 2000; Sheffer, 2011; Hall et al., 2020)

Emerging Structures - From Project-Based to Product-Based Strategies

Recent scholarly works have begun to interest the emergent structures that firms are using to integrate modular construction and industrialize their construction processes (e.g. Lessing, 2019; Hall, 2018; Hall, et al. 2022). A significant shift is underway in the construction sector, moving from project-based to product-based strategies. This transition is primarily motivated by a need for greater efficiency and standardization within the industry (Sheffer, 2011; Lessing, 2019; Hall et al., 2020). Traditional methods, such as the 'Decentralized Modular Clusters' approach, are gradually being replaced by more integrated 'Supply Chain Integration Practices' (SCIPs). SCIPs, which include innovative tools like Building Information Modelling (BIM) and Target Value Design, are part of a strategic shift in the industry (Azhar, 2011; Ballard, 2008; Hall et al., 2018).

During this shift, the concept of *partial mirroring* emerges as a crucial consideration. To overcome this challenge, firms need to expand their knowledge beyond their specific tasks and incorporate a broader understanding of technologies (Hall et al., 2020). This is especially important for system integrators who oversee the performance and development of entire technical systems and their network suppliers. As technology advances at a faster pace and systems become more complex, firms may choose to pursue an alternative strategy called mirror breaking (Hall, 2018). This strategic approach involves using relational contracts to encourage high levels of communication and cooperation across boundaries or employing pre-emptive modularization to create new, modular technical architectures (Baldwin and Clark. 2000; Colfer and Baldwin, 2016).

Despite the potential benefits of these shifts and new strategies, they are not without substantial challenges. The transition requires significant cultural shifts, an enhanced technical skillset, and considerable investments in technology (Azhar, 2011). These challenges have yet to be comprehensively addressed in existing scholarly literature, indicating a significant opportunity for further research and exploration in this area.

Problem statement

The potential of industrialized and modular construction methods to elevate environmental sustainability and productivity in the construction sector is well acknowledged (Lessing, 2015).

These methods, in comparison to conventional construction practices, offer significant advantages that have been extensively explored in scholarly research (Abdelmageed and Zayed, 2020; Feldmann, Birkel, and Hartmann, 2022). Current knowledge also confirms that industrialized construction can address the fragmentation issues in the construction and real estate industries, creating potential for standardization, transparency, and consistency across regions and market segments (Sheffer, 2011; DiPasquale and Wheaton, 1996).

Despite the considerable body of research, there is a significant gap in understanding the role of real estate developers in the integration of these construction methods (Bertram et al., 2019; Ribeirinho et al., 2020). This stakeholder group, which plays a pivotal role in influencing the choice of construction systems and driving the construction market, remains underrepresented in current research. Moreover, the impact of standardized industrialized real estate products on the typically regional, sectoral, and cyclical fragmentation of the real estate market remains an area requiring further exploration (Goodman and Thibodeau, 1998; Wheaton, 1999).

Addressing this research gap is crucial due to the influential role of project developers in the real estate sector. They could serve as potential catalysts for the successful integration of industrialized and modular construction concepts, thereby transforming conventional construction practices (Lessing, 2015; Feldmann, 2022). By investigating their perspectives and roles, we can develop strategies to overcome barriers to the widespread adoption of these methods. Ultimately, the exploration of this gap could contribute to the transformation of the real estate sector, fostering increased sustainability, productivity, and integration. This proposed research aims to fill this gap and contribute to a more comprehensive understanding of the complexities involved in the shift towards industrialized construction methods in the real estate sector.

Research foundation

This section lays out the foundational aspects of the thesis, namely, the research questions that this study seeks to answer and the conceptual framework guiding this exploration. These two aspects are crucial as they provide a clear path for the research and dictate the approach that will be followed.

Research questions

3.1 Research Questions
This study aims to delve into the significant and transformative role of real estate developers in integrating modular construction techniques within their business operations, and how this integration could stimulate broader adoption of industrialised construction methods within the real estate development sector. With the modular construction market projected to witness substantial growth, this research seeks to explore the dynamics and possibilities of this integration in a strategic manner. The research questions formulated for this study are meticulously designed to scrutinise the aspects of current practices, challenges and drivers, and the strategic and proactive role of real estate developers.

The Main Research Question (MRQ) is:

"How does and how can real estate developers strategically integrate modular construction in adopting industrialised construction?"

The intent of this question is to uncover the strategic ways through which real estate developers can not only align their business operations with modular construction techniques, but also champion the cause of industrialised construction in the sector.

To further examine the main research question, the following sub-questions are proposed:

Sub-question 1: "What are the current strategies and mechanisms used by real estate developers for integrating modular construction in their operations?" This sub-question aims to capture the present landscape of modular construction integration in the sector. It will illuminate the prevalent strategies and mechanisms utilised by developers, thus laying the groundwork for identifying potential areas for strategic enhancement.

Sub-question 2: "What are the challenges and drivers influencing the adoption and enhancement of modular construction strategies?" This sub-question is designed to analyse the factors that are influencing the adoption of modular construction within a certain strategic approach. Unravelling these elements can facilitate a more nuanced understanding of the landscape and inform strategies for overcoming obstacles and leveraging drivers.

Sub-question 3: "How can real estate developers play a more strategic and proactive role in advancing the broader adoption of industrialised construction?" This final sub-question addresses the pivotal role of developers beyond their business boundaries. It aims to identify the ways in which they could act as catalysts for broader change, encouraging more widespread adoption of industrialised construction methods throughout the industry.

These questions collectively create a comprehensive framework for exploring how real estate developers can strategically foster the integration of modular construction, thus promoting industrialised construction on a larger scale.

Conceptual Framework

The conceptual framework suggests that real estate developers' integration strategies (independent variable) directly affect their modular construction methods (dependent variable) as shown in Figure 4. However, this relationship is moderated by the mechanisms developers employ in applying these strategies. These mechanisms can adjust the impact of integration strategies on modular construction. This framework serves as the theoretical lens through which the research questions will be examined.

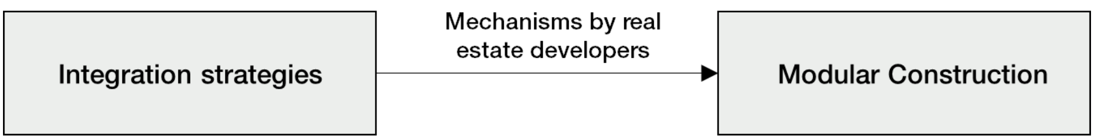

Figure 4: Conceptual framework

- **Integration Strategies:** The first part of the framework pertains to the different methods that real estate developers can employ to incorporate modular construction into their business. Understanding these strategies will provide insights into effective practices for modular construction integration and potential improvement areas.
- **Mechanisms by Real Estate Developers:** The second part involves the specific processes or steps that real estate developers use to implement their chosen integration

strategies. The study of these mechanisms will help identify best practices, common trends, and potential challenges in the application of modular construction methods.

- **Modular Construction:** The final part of the conceptual framework focuses on modular construction itself. By studying this aspect, the research can determine how real estate developers can best exploit the advantages of modular construction and mitigate its challenges.

This conceptual framework forms the structure of the theoretical frame of reference that informs the research method, shaping both the direction and methodology of the study. It ensures a structured, focused, and comprehensive approach to investigating how real estate developers integrate modular construction within their businesses.

2

Theoretical frame of reference

Modular Construction, Integration strategies and mechanism by real estate developers

> *Industrialized construction includes a new strategic orientation that develops long-term relationships between participants, integrates advanced supply chain management and logistics, designs new technical systems that better support manufacturing and assembly activities, captures experience and knowledge for continuous improvement, improves the planning and control of processes, and increases understanding of customer requirements and market forces. In other words, industrialized construction is an entirely new strategic approach for the construction sector. This new strategic approach opens an opportunity for the development of new business models that can capture value from a new way of thinking about construction.*
>
> *(Hall, Lessing, and Whyte, 2022, p.15)*

Understanding Modular construction

This section provides a consecutive understanding of modular construction, starting from its roots in industrialization and standardization, its historical development, its relevance to offsite construction, to its various challenges and benefits. The chapter is aimed to give a comprehensive understanding of this transformative construction method.

Industrialisation

Contemporary manufacturing techniques, such as centralized labour planning and automated production systems, have significantly transformed the way individuals communicate and interact with their environment (Lessing, 2015). The term "industrialization" varies depending on the context and time, deviating from its current interpretation. Historically, industrialization denoted the shift from agrarian to industrial societies during the 18th and 19th centuries in Europe and America (De Vries, 1994). Nowadays, it also refers to similar transformations in developing countries, as well as the digitization and automation processes in the context of Industry 4.0 (Schwab, 2017). Thus, the interpretation of "industrialization" varies based on context and time. Furthermore, this concept covers multiple aspects, including mechanization for improved efficiency and consistency, work execution in off-site factories, and task coordination within companies and between organizations (Lessing, 2015; Hewitt and Wield, 1992).

Hewitt (1992) defined industrialization as "a particular way of organizing production and assumes there is a constant process of technical and social change which continually increases society's capacity to produce a wide range of goods" (Hewitt et al. 1992 as cited in Kiely, 2005). This definition considers industrialization as a change typically accompanied by significant shifts in social structure, supply chains, and collaboration due to alterations in labour and material force distribution. In the literature (e.g., Gan, 1996; Lessing 2006; Grenzfurtner and Gronalt, 2021), this modern understanding of industrialization is often traced back to Henry Ford's Model T. Ford pioneered mass production in the United States in the early twentieth century, and his approach influenced standardization and optimization of the manufacturing process (Gan, 1996). This operation required less specialized labour in production while maintaining high-quality output (Johnson and Broms, 2000). Furthermore, they note that research suggests such manufacturing is less expensive for end-users, but the degree of variation is much lower compared to traditional production.

When discussing industrialization, the concepts of standardization, repetition, and modularization are frequently mentioned (Johnson and Broms, 2000; , Lessing 2006; Lessing et al., 2015). Hence, these notions are initially briefly outlined in the context of industrialization in general. The subsequent section will aim for a more detailed description in the context of industrialized construction.

Standardization, repetition, and modularization

Gibb (2001) defines standardization as the process of creating and implementing standards that enable the mass production of components that can be easily exchanged with other parts without requiring any modifications. Gibb (2001) points out that standardization is not solely about technically increasing productivity, but also about redefining processes, methods, and collaboration forms. He describes standardization as follows:

> *Standardisation is the extensive use of components, methods, or processes in which there is regularity, repetition, and a background of successful practice and predictability. (Gibb, 2001, p. 308)*

Lessing (2019) states that standardization can be achieved by optimizing size, dimensions, and interfaces while also limiting variety, ensuring interchangeability, compatibility, and flexibility. Other benefits (and drivers) of standardization include waste, time, and resource optimization and facilitating clear communication between suppliers. Repetition is not the primary goal of standardization; the main advantage is the output of a transparent workflow with minimal failures (Johnson and Broms, 2000; Lessing, 2019).

Modularization, a principle originating from standardization and interchangeability in industrial production, involves dividing a system or structure into standardized, interchangeable modules, thereby facilitating cost-effective manufacturing of diverse machine or structure variants (Johnson and Broms, 2000). This design principle enables progressive development and automation of assembly systems, bringing multiple benefits including reduced lead times, diminished work in progress, fewer vendors, improved assembly ergonomics, and continuous product renewal and scalability (Lessing, 2006).

A prime example of modularization is Scania, a heavy truck manufacturer. They employ an innovative modular design system that enables any engine to be compatible with any truck chassis. The modular design is subdivided into sub-modules, allowing for customer-specific adjustments without compromising the core modular design concept. This flexibility results in additional configurations tailored to meet individual customer requirements. This successful application of modular design has resulted in Scania achieving consistently high profit margins, more so than any other truck manufacturer globally (Lessing, 2006).

Industrialization of construction

The literature on industrialized Construction contains numerous definitions that vary across countries and over time (Kiely, 2005; Aitchison et al., 2018; Bertram et al., 2019; Lessing, 2019; Hall et al., 2022). In essence, these terminologies differ in technique or method. At the beginning of the industrialization of construction in the early 1900s, the definition was mainly sought in system construction, building with prefabricated elements, and mainly focused on production. As with industrialization in other industries (see section above on industrialization), the emphasis is primarily on off-site construction of components rather than traditional on-site construction. By establishing factories, benefits can be realized in the areas of standardization by the production of (small) prefabricated modules. As a result, the industry will be much more productive in the long run (Lessing, 2019). Lessing (2016, p. 63) presented in his research a rather old definition from 1965:

> *"Industrialization of construction activities include a striving to develop and make the production effective, regarding quality and economy by the use of scientific knowledge, repeating work processes in factories, design offices and at building sites, and by the co-ordination of different activities within and between companies"*

However, this definition recasts a more obsolete idea of industrialized construction, which was primarily cantered on mass manufacturing and system construction using prefabricated pieces. Therefore, Aitchison et al. (2018) argue in their book: ‘Prefab Housing and the Future of Building: Product to Process’ that we should rather look at the common characteristics, output, and outcomes of industrialized construction rather than resolve disagreements about terms and definitions. Industrialization in the construction sector comprises standardization of both materials and processes, prefabrication and a significant emphasis on offsite manufacturing, platform-based approaches, and to give the value-adding activity a positive impulse in the supply chain (Gawer, 2009; Oprach et al., 2019; Jones et al., 2021).

Lessing (2019) notes that industrialized housing has only been a more widely supported place to go since the beginning of the 21st century when traditional methods were no longer sufficient. However, this standardized method in itself is not sufficient for structural adoption. According to Girmscheid (2005), the success of industrialization adoption depends on product-oriented and customer-oriented adaptations that are streamlined in the production and processes.

Industrialized Construction places its primary emphasis on the offsite production of components, moving away from traditional onsite building methods (Gawer, 2009; Jones et al., 2021). This shift leads to the adoption of offsite construction (OSC), where a significant portion of the construction work takes place in factories. Building components are manufactured offsite and then transported to the construction site for final assembly (Gibb, 2001). Modular Construction is an example of OSC, where a substantial portion (ranging from 80% to 95%) of a building's construction occurs in an offsite factory environment (Smith, 2016; Pan and Hon, 2020).

Daniel Hall (2020) and Jerker Lessing (2019) states that, contrary to common belief, industrialization in the construction sector extends beyond a mere strategy to transition from On-Site Construction (OSC) to advanced production within a controlled factory environment. This prevalent misinterpretation often results in the erroneous interchange of terms such as off-site production, prefabrication, or modular construction with industrialized construction (Blismas and Wakefield, 2009; Hall et al., 2022). However, this thesis adopts a more encompassing and holistic view of Industrialized construction that extends beyond the confines of the production process.

Industrialized construction, as conceived in this thesis, encapsulates a strategic shift that fosters enduring relationships among stakeholders, integrates advanced supply chain management and logistics, and fosters the design of technical systems that enhance production and assembly activities (Hall, 2020). In simple terms, it involves gathering experience and knowledge to continuously improve, enhancing the planning and control of processes, and gaining a better understanding of customer needs and market dynamics (Lessing, 2015). In essence, Industrialized Construction represents a transformative strategic approach for the construction sector.

In framing the reference of this study, various facets of industrialized construction will be examined independently to facilitate a thorough comprehension of the diverse components involved. This approach offers an opportunity to create innovative business models that can generate value by bringing a fresh perspective to the construction industry (Hall et al,. 2022).

Industrialized construction which finds relevance in areas with high housing demand and a shortage of construction workers, is not a new concept but has its origins in the mid-20th century (Bertram et al., 2019). Bertram et al. (2019) conducted an analysis of its historical usage in the United States and the United Kingdom, highlighting the significant role of demand dynamics in these countries. Figure 5 provides an overview of these demand dynamics.

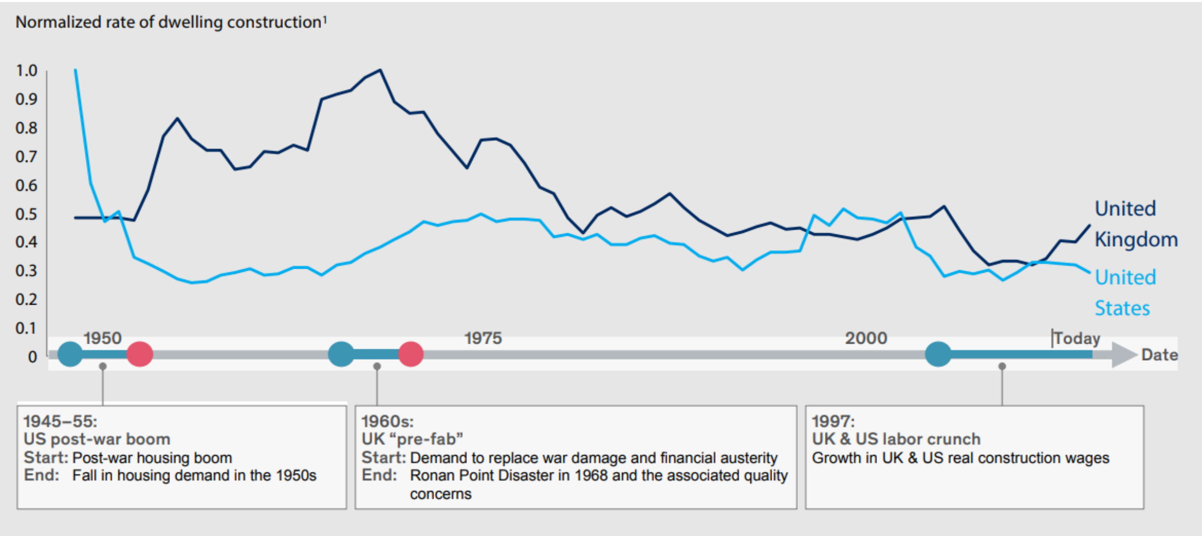

Figure 5: Normalized rate of dwelling construction, adopted from McKinsey Capital Projects and Infrastructure analysis (adopted from Bertram et al., 2019).

In the aftermath of World War II, there was a notable surge in industrialized construction in the Netherlands and other parts of Europe. The urgent need for rapid construction of social housing, combined with the limited resources and labor force availability in the post-war period, paved the way for this approach. However, the collapse of the Ronan Point apartment tower in East London in 1968 raised concerns about the safety of prefabricated structures, leading to a decline in the popularity of high-rise social housing tower blocks in the UK (Bertram et al., 2019; Lessing, 2019).

Over the years, the popularity of IC has experienced fluctuations. Its adoption and integration process can be heavily influenced by individual incidents. Nevertheless, several scholars (Akintoye, McIntosh, and Fitzgerald, 2000; Girmscheid, 2005; Aitchison et al., 2018; Lessing, 2015; Bertram et al., 2019) argue that this method may prove to be more enduring this time due to its contemporary benefits. Industrialized Construction is increasingly recognized for its potential in promoting circularity, bio-based construction, and digitization (Bertram et al., 2019) which will be elaborated on in the next section.

Offsite construction

Off-Site Construction (OSC) is emerging as a progressive development in the realm of Industrialised Construction, gaining traction for its capacity to transform traditional construction processes. In this method, a considerable portion of the construction activities are moved from on-site locations to controlled factory environments, marking a substantial departure from conventional construction methodologies (Gibb, 2001).

The advantage of this approach is that building components can be manufactured in controlled conditions before being transported to the construction site for final assembly. This results in improved efficiency, reduced waste, and better quality control, leading to superior construction outcomes (Kamali and Hewage, 2016; Gibb and Isack, 2001).

To illustrate, a construction company is tasked with building a residential complex. Rather than constructing the walls of each unit on-site using traditional methods, they opt for off-site construction. In this scenario, the wall panels are manufactured in a controlled factory environment, where quality can be rigorously overseen. Once completed, these wall panels are transported to the construction site and assembled. This approach results in significant reductions in the required time and labour for the project.

In the construction industry, standardization plays a crucial role in determining the level of component and system production and pre-assembly that occurs in a factory before being transported to the construction site (Gibb and Isack, 2001;Lessing, 2019). This concept encompasses different categories, each representing a distinct level of assembly and integration. The classifications of standardization in construction can be summarized in the following table:

Classification	Description
Component assembly	Creation and assembly of smaller elements, such as windows, in a factory setting.
Non-volume preassembly	Production and assembly of products in a factory environment to create non-volume units, such as walls.
Volume preassembly	Production of volume units, like fully finished bathrooms, with usable space and internal finishing before being transported to the site.
Modular building	Production and assembly of complete buildings or entirely finished units in a factory setting for transportation to the construction site.

Modular construction, a subset of standardization, further categorizes the assembly types based on the specific characteristics of the modules. These assembly types provide a more nuanced understanding of the modular construction process and its application in different building projects:

Classification	Description
1D modular	Linear assembly of prefabricated components.
2D modular	Horizontal and vertical assembly of complete wall systems.
3D modular	Stacking or combining modules to construct entire structures.
Hybrid modular	Combination of different techniques for flexible construction.

These classifications provide a framework to understand the different levels of standardization and modular construction within the construction industry (Taylor, 2010; Pan and Hon, 2020; Kamali and Hewage, 2016). Often, these categories overlap within modular building projects, typically concentrating on the use of 3D volumetric units for off-site construction as shown in Figure 6.

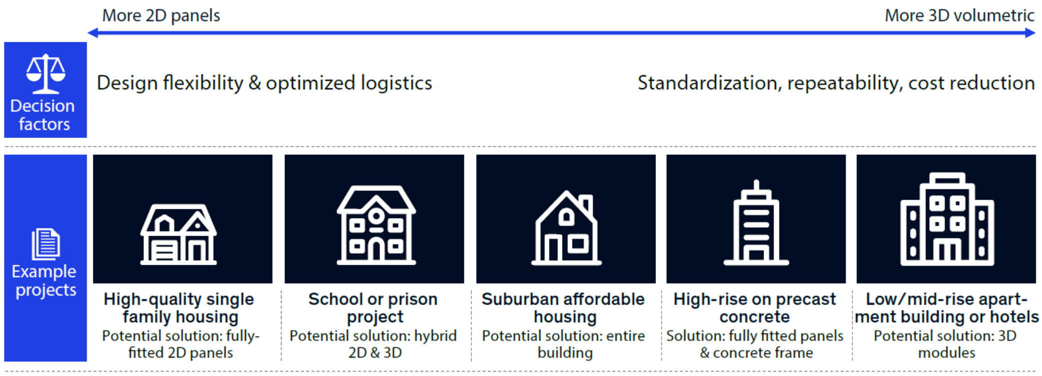

Figure 6: Project requirements dictate modular system selection. adopted from McKinsey Capital Projects and Infrastructure analysis (Bertram et al., 2019).

The examples of Singapore and Hong Kong, with their respective MiC (Modular Integrated Construction) and PPVC (Prefabricated Prefinished Volumetric Construction) approaches, demonstrate the increasing significance of modular construction in the global construction industry (Pan and Hon, 2020). These markets have emerged as pioneers in adopting modular construction methods to improve efficiency, shorten construction timelines, and reduce labour-intensive tasks. Through the prefabrication of a substantial portion (up to 90%) of construction activities in regulated off-site facilities, these approaches extend beyond individual modules to encompass volume designs (Pan and Hon, 2020).

Nevertheless, a critical evaluation of the challenges associated with the utilization of prefabricated and precast elements in modular construction is essential. These challenges stem from the distinctive characteristics of modular construction and the specific contexts of each market. By analysing these challenges, we can gain a deeper understanding of the complexities and limitations that must be addressed for successful implementation.

Benefits and challenges

Modular construction has become increasingly popular as a means to improve the efficiency, sustainability, and cost-effectiveness of the construction industry (Smith, 2016). This section discusses the benefits and challenges of modular construction, providing a balanced perspective on its potential impact on the future of the construction sector. Given the extensive scholarly discourse surrounding the benefits and challenges, this thesis will strive to offer a comprehensive yet selective summary.

Benefits of modular construction

Modular construction presents a wide range of advantages compared to conventional on-site construction approaches, making it an attractive option for diverse project types. In this section, we offer a comprehensive summary of the well-established benefits associated with modular construction. These insights are derived from extensive literature reviews and research studies, as outlined in Table 1.

Table 1: Advantages of modular construction

	Name of Benefit	Short Description	Literature
B1	Cost Reductions	Modular construction reduces labor costs, accommodation expenses, and maintenance costs	Fagerlund, 2001; Gotlieb et al., 2001; Al-Hussein et al., 2009; Bertham et al., 2019; Hammad et al., 2019
B2	Improved Schedule Performance	Modular construction enhances schedule performance and reduces construction time	Tsz Wai et al., 2021; Bertham et al., 2019
B3	Enhanced Quality	Modular construction offers better quality control and assurance	Bertham et al., 2019;
B4	Increased Safety Performance	Modular construction provides safety benefits by reducing on-site risks	O'Connor, 2015; Bertham et al., 2019; Lawson et al., 2012; Tsz Wai et al., 2021;
B5	Reduced Waste and Improved	Modular construction reduces waste, promotes sustainability	Lawson and Ogden, 2010; Tsz Wai et al., 2021; Lawson et al., 2012; MBI, 2010
B6	Environmental Performance	Decreases CO2 footprint, nitrogen emissions and adopts biobased materials.	Van der lugt (2020); Pervez, Ali and Petrillo (2021)

In conclusion, modular construction offers a range of proven benefits, including cost reductions, improved schedule performance, enhanced quality, increased safety, and reduced waste. These advantages make it an attractive option for various projects, providing potential solutions to challenges faced by traditional construction methods. By adopting modular construction techniques, stakeholders can benefit from the economic, operational, and environmental advantages supported by research and industry experience.

Challenges of modular construction

Despite its many benefits, modular construction also comes with challenges that must be addressed for successful implementation. Table 2 provides an overview of these proven challenges, drawing from existing literature and research studies. By understanding and tackling these challenges, stakeholders can ensure the effective utilization of modular construction and capitalize on its advantages.

Table 2: Challenges of modular construction

Number	Challenge	Short Description	Literature

C1	High initial investment	Modular construction requires a significant start-up cost for setting up the necessary manufacturing facility	Kamali and Hewage, 2016; R. Lawson and Ogden, 2010; Ferdous et al., 2022; Rippon, 2011
C2	Coordination	Effective coordination among stakeholders is essential for successful execution of modular construction projects	Hořínková, 2021; Kamali and Hewage, 2016; Azhar et al., 2013
C3	Early Design Freeze	Modular construction often requires an early design freeze, limiting customization options	Choi, 2014; Rahman, 2014; J. O. Choi, 2014
C4	Logistics	Transportation logistics pose challenges in moving modules from the manufacturing facility to the construction site	Hořínková, 2021; Liu et al., 2019; Bertham, Fuchs, et al., 2019
C5	Competency	Availability of skilled personnel and the lack of market demand for modular construction can hinder competency development	Rahman, 2014; Hořínková, 2021

In conclusion, modular construction brings numerous benefits but also presents challenges that must be carefully addressed. These challenges include high initial investment, coordination among stakeholders, early design freeze, logistics, and the competency of personnel. By effectively planning, coordinating, and investing in training, these challenges can be overcome, maximizing the benefits of modular construction.

Integration strategies

Industrial paradigms for modular construction

Before elaboration on the integration strategies, it is important to introduce a selection of relevant paradigms for modular construction and how they relate to this research.

Paradigm: Traditional project management and modular construction

Traditional project management has long been the cornerstone of the construction industry, founded upon key principles like the triple constraint theory or the "Golden Triangle". This model emphasizes the inherent trade-offs between the three constraints of scope, time, and cost, with quality placed at the centre.

As depicted in Figure 7, the triple constraint model suggests that if any one constraint is adjusted, it invariably impacts the other two. For instance, expanding the scope may require more time and increase costs, while tightening the timeline could result in either a reduction in scope or a surge in costs (Van Wyngaard, Pretorius, and Pretorius, 2012). The intersection of these constraints – time, cost, and scope – ultimately governs the quality of the final project outcome (Van Wyngaard, et al., 2012).

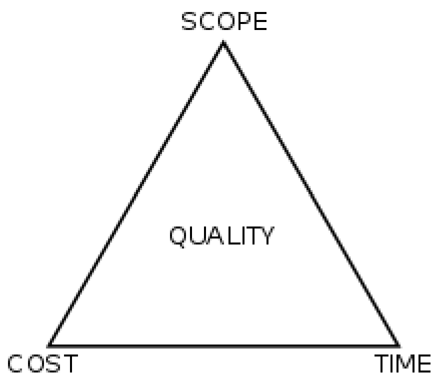

Figure 7: Triple constraint model (adopted from Van Wyngaard, Pretorius, and Pretorius (2012).

The conceptual shift from traditional project-based construction management to the integration of project-based management has marked a significant pivot in the industry. This shift implies a transition from a flexible design approach to one that emphasizes standardization, challenging the traditional notion of the triple constraint theory (Van Wyngaard, et al., 2012).

The project-based approach, traditionally employed in construction, commences with a largely blank canvas, with unique design outcomes achieved within specific project constraints. Despite the inherent value generated for the client, this value tends to diminish as each unique project concludes and temporary teams disband, with potentially valuable skills and knowledge not necessarily transferred to the subsequent project.

Contrastingly, Product-based management involve the assembly of standardized building modules manufactured in controlled off-site environments, akin to assembly line production observed in other industries such as automotive manufacturing. This fundamentally changes the design and delivery process, with a focus on product outcomes rather than specific project deliverables.

The core of a modular construction design is the building block, or module. Unlike the project-based approach, which tailors to specific client requirements, the modular approach markets its product and capabilities to prospective clients (Bertham, et al., 2019). Product-based management also fosters long-term partnerships with architects, suppliers, and manufacturers, and facilitates a continuous learning and improvement cycle through regular feedback. The standardization of elements and building blocks typically created through in-house RandD functions simplifies the process and promotes continuous improvement due to repetitive practices (van der Ham and Opdenakker, 2021).

The transition to modular construction techniques challenges the traditional project-based approach, advocating instead for a product-based methodology that capitalizes on the industry-wide standardization of modules and components (Bertham et al., 2019). This approach potentially strikes a balance between common, industry-standard features and customizable aspects to meet individual customer requirements (Hall et al., 2020)

In summary, the transition from project-based to product-based construction management has notable implications for traditional construction practices as shown in

Table 3. It marks a shift towards standardization, and fundamentally reshapes the "Golden Triangle" of construction project management.

Table 3 : Differences between Project-Based and Product-Based Management

-	**Project-Based Management**	**Product-Based Management**
Approach	Unique, flexible design per project	Standardized, modular design
Focus	Delivery of specific project deliverables	Creation of a standardized product
Learning and Progress	Skills and knowledge may not transfer from project to project	Continuous improvement and learning from feedback
Partnerships	Temporary teams for each project	Long-term partnerships with architects, suppliers and manufacturers
Value	Delivers unique value to each client and project	Delivers value through a standard product
Development	Begins with a blank canvas	Begins with a set of standardized modules

Paradigm: Agile Project Management in modular construction

Agile project management is a flexible and step-by-step approach to project management that has become popular in various industries, including construction. It projects breaks down into small, manageable parts, allowing for adjustments and refinements at each stage. Agile methodologies are cantered on principles of collaboration, flexibility, customer involvement, and delivering high-quality results (Highsmith, 2009).

In the context of the shift from traditional project-based construction management to product-based management with a focus on modular construction, agile principles could offer significant benefits. As opposed to the traditional Golden Triangle where scope, time, and cost constraints govern the quality of the project, agile management introduces flexibility within these constraints.

Agile management prioritize collaboration and adaptability. This approach would align with the product-based management style of modular construction. It would allow for continuous feedback and improvements in the product, optimizing both the design and construction process (Conforto, Amaral, da Silva, Di Felippo, and Kamikawachi, 2016).

As depicted in Table 3, agile project management would influence various aspects of both project-based and product-based management. For instance, in project-based management, agile principles could facilitate more efficient use of resources and improved adaptation to changes in project requirements. On the other hand, in product-based management, agile could foster continuous learning and improvement by incorporating customer feedback into the product development process.

However, the successful application of agile methodologies in construction, particularly in modular construction, requires a commitment to long-term partnerships between all stakeholders, including architects, suppliers, manufacturers, and clients. With such commitment, the repetitive cycle of modular construction could be enhanced by agile principles, resulting in better product outcomes, increased customer satisfaction, and continual organizational learning (Aziz and Hafez, 2013).

In conclusion, the incorporation of agile project management principles within the emerging paradigm of modular construction and product-based management could lead to improved efficiency, quality, and customer satisfaction. As the construction industry continues to evolve, such innovative management approaches will become increasingly important Conforto et al., 2016).

Paradigm: Integrated project delivery and value systems

Integrated Project Delivery (IPD) is a collaborative business model that seeks to draw upon the combined expertise and knowledge of all project participants. It emphasizes the principles of collaboration, shared risk and reward, mutual trust, value-oriented decision-making, and open communication. This model becomes particularly relevant in the context of modular construction, where industrialized processes demand enhanced integration and alignment among project stakeholders (Jones, 2014). Distinct from traditional, fragmented methods of project management, IPD promotes a streamlined workflow where design and construction processes take place concurrently. This simultaneous progression accelerates project timelines, fostering greater operational efficiency and cost-effectiveness. IPD aligns the objectives of diverse stakeholders, encouraging a holistic understanding of the project and driving innovation and quality enhancement (Kent and Becerik-Gerber, 2010).

To understand the role of IPD in modular construction, it's crucial to comprehend the nuances of supply chain and value chain (see Table 4). The supply chain refers to the network of organizations, resources, and activities involved in moving a product or a service from supplier to customer. It concentrates on the effective and efficient transfer of materials, information, and finances (Vrijhoef and Koskela, 2000).

On the other hand, the value chain deals with the sequence of activities an organization undertakes to create value for its customers. Each activity in the value chain adds value to the product or service, thereby enhancing its overall worth to the consumer Ponte and Sturgeon (2014). The value chain in construction is inherently a process-oriented concept, involving a series of interconnected activities that add value to the final product, for example the modular construction. The process perspective allows us to understand how each activity contributes to the value creation and how the activities can be coordinated and integrated to enhance the overall value creation. Thus, studying the value chain from a process perspective is critical to achieving efficiency, quality, and customer satisfaction in construction (O'Brien, London, and Vrijhoef, 2002).

In construction, the primary activities typically include design, procurement, fabrication, assembly, and post-assembly services. The support activities may include human resource management, technology development, procurement management, and infrastructure management. The construction value chain, thus, represents a series of activities from conceptual design to post-assembly services that add value to the final product (O'Brien et al., 2002).

Table 4: Supply Chain and Value Chain Management in Construction

	Supply Chain Management in Construction	**Value Chain Management in Construction**
Focus	The primary emphasis is on effectively managing and coordinating the movement of materials, information, and finances between suppliers and customers (Christopher, 2016).	Centres on the sequential activities and processes in the construction project that add value to the final product, from conceptual design to post-assembly services (O'Brien et al., 2002).
Key Elements	Suppliers, manufacturers, construction companies, and customers (Christopher, 2016).	Design, procurement, fabrication, assembly, and post-assembly services (O'Brien et al., 2002).
Orientation	Flow-oriented, emphasizing the efficient flow of materials, information, and finances (Christopher, 2016).	Process-oriented, emphasizing the value-adding activities and processes (Porter, 1985).
Goal	Efficiency in the flow of resources to minimize costs and maximize profits (Christopher, 2016).	Maximize value creation for customers through integrated and coordinated activities (Porter, 1985).
Integration	Involves the coordination among different entities in the supply chain, often through contractual agreements and information sharing (Christopher, 2016).	Involves the integration of various activities within the construction project to enhance overall performance and customer value (Arashpour et al., 2016).

The conventional construction value chain involves a linear sequence of activities, often with little integration among the activities. In contrast, the industrialized construction value chain, as exemplified by modular construction, involves a more integrated approach, with activities being coordinated and overlapped to enhance efficiency and quality (Blismas and Wakefield, 2009).

One of the main advantages of the modular construction value chain is the potential for mass production and standardization, which can lead to significant cost and time savings. Moreover, the controlled factory environment allows for better quality control and waste minimization. However, it requires a higher level of coordination and integration among the activities and stakeholders (Blismas and Wakefield, 2009).

Value chain integration in construction involves linking and coordinating the various activities in the value chain to enhance overall performance and create superior value for the customers. This can be achieved through strategies such as early involvement of stakeholders, use of digital technologies for coordination, and continuous improvement of processes (Arashpour et al., 2016).

These chains are not separate entities but rather interrelated systems influencing each other. In modular construction, the interplay between these chains is vital. As Table 8 demonstrates, the process map of a traditional company. construction model typically entails the client's planning, carried out by an architect or general planner, followed by the engagement of a general contractor for construction services. This model results in the dispersion of design and planning responsibilities at the project level, following a linear system. Figure 9 illustrates an industrialized construction company includes various phases from design, manufacturing, to installation. incorporates Design for Manufacture and Assembly (DfMA) into the services provided by the General Contractor. The General Contractor creates standardized concepts for an entire product family at the company level, which are then applied to individual projects. In every project, the customer provides their specific requirements, and the contractor tailors a product to fulfil those needs. Through promoting collaboration between the development of firm-level platforms and the implementation of project-level tasks, the company establishes feedback loops to drive ongoing enhancements (Müller, 2021). This iterative learning approach allows for the optimization and ongoing updates of the platform based on the outcomes of each project, thus generating valuable insights for future endeavours. Each phase requires distinct inputs and contributes to the generation of a valuable output, such as a modular construction unit, through collaborative efforts.

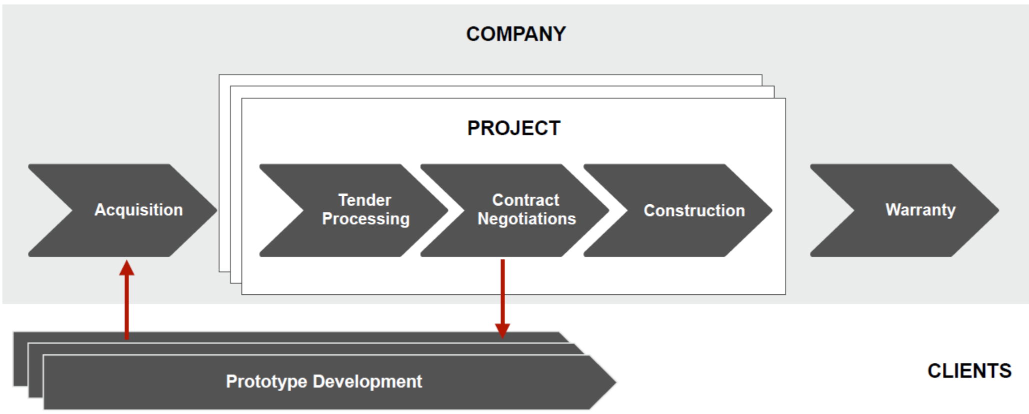

Figure 8: A process map illustrating the workflow of a traditional construction company (adopted from Müller, 2012).

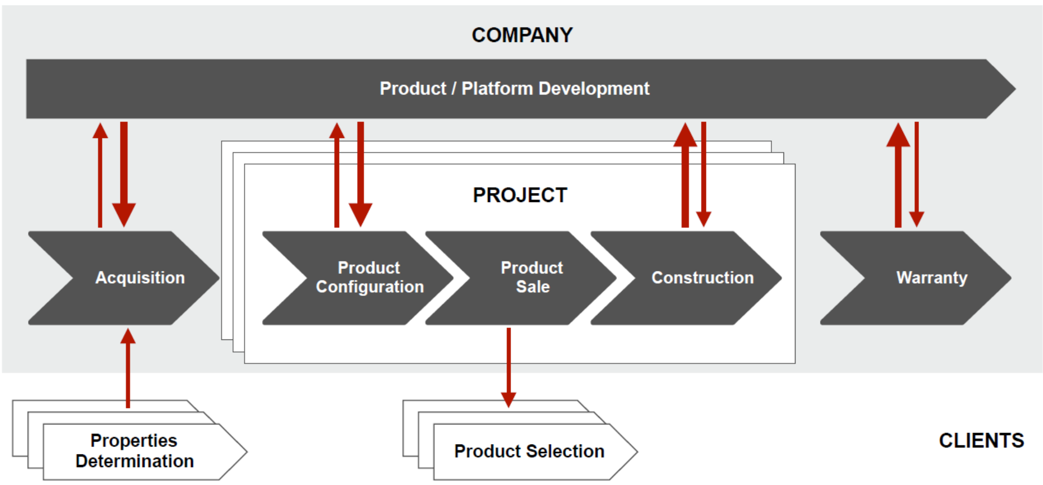

Figure 9: process map depicting the workflow of an industrialized construction company (adopted from Müller, 2012).

As depicted in Figure 10 project-level productization necessitates early planning and limits flexibility in client changes. However, it streamlines the design process and reduces the effort in planning.

Industrialized Construction (IC) offers key benefits such as faster project completion by shifting

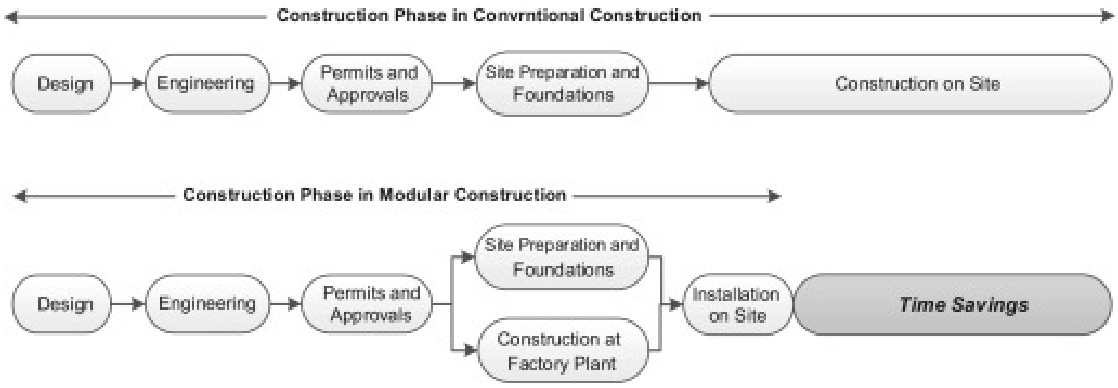

Figure 10: traditional and modular construction process (adopted from Kamali and Hewage, 2016)

from on-site work to off-site manufacturing. It allows parallel construction activities and the pre-fabrication of elements independent of the project. Automated tools aid in efficient assembly of these elements, potentially accelerating the construction process by up to 50% (Müller, 2021; Kamali and Hewage, 2016)

Paradigm: production systems for Modular construction

A "manufacturing model" pertains to a system custom-fitted to a designated product and the corresponding production method. The determination of these models is influenced by the "decoupling point," an element in the value chain receptive to customer necessities. This point allows customers to specify their product preferences, parameters, protocols, or individualized alterations for the final product (Segerstedt and Olofsson, 2010). The manufacturing model holds a crucial role, impacting both the proficiency and productivity of the manufacturing process substantially.

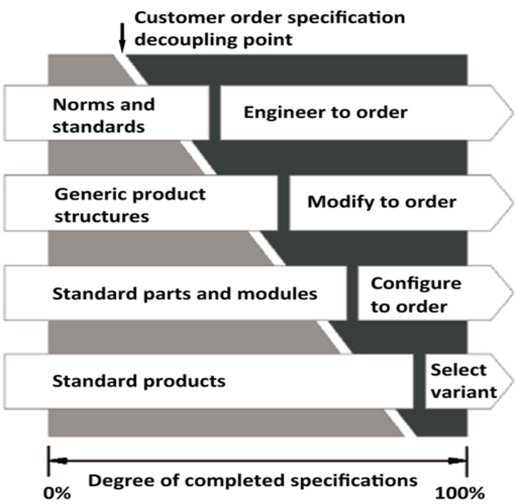

Figure 17. The decoupling point guiding the strategy of the production system (adopted from Seppala Kenney, Ali-Yrkko, 2014)

As shown in Figure 17, the decoupling point constitutes a moment within the production system where customer specifications may be either unknown or considered irrelevant. This consideration of the decoupling point is essential when deciding the type of production system to employ. Traditional manufacturing encompasses four main strategies: make-to-stock, assemble-to-order, make-to-order, and engineer-to-order. These strategies stipulate the extent of a customer's order impact on the production process (Rajagopalan, 2002). The transitional point between make-to-order and make-to-stock is referred to as the decoupling point. Within this system, the integrator does not complete a product for storage, regardless of the absence of known end-users (Segerstedt and Olofsson, 2010).

Construction innovation

The construction industry has traditionally been anchored in conventional methods, which has frustrated its potential for innovation (Lessing, 2019). Nevertheless, alternative innovation such as MODULAR CONSTRUCTION have emerged, challenging the status quo. Adopting such strategies involves an overhaul of the conventional construction process to align with modular principles. However, the transformation is not about simply merging new methods with the old; it calls for a more profound development of methods and techniques. Literature debates whether innovation is driven by technology (supply) push, emphasizing technological development, or demand pull, focusing on market profitability opportunities (Sheffer, 2011). Martin (1994) graphically illustrates this division (Figure 11).

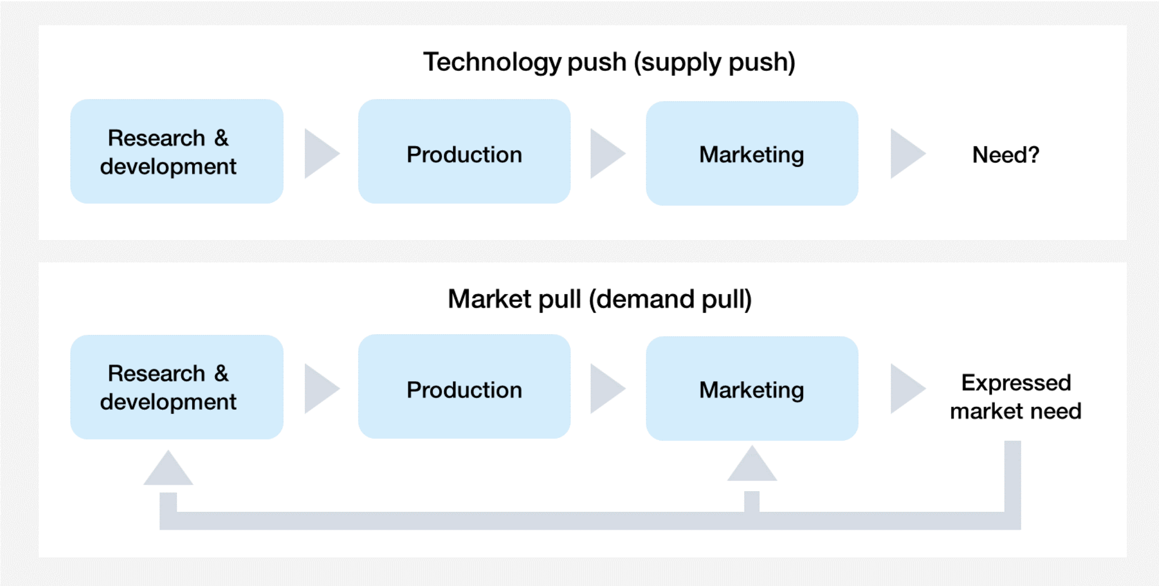

Figure 11: Technology-push versus Market-pull (adopted from Martin 1994, p44)

The technology-push hypothesis suggests that innovation originates from internal research and development efforts, without considering market demand. In this model, new products are created and then marketed to generate demand. On the other hand, the market-pull hypothesis suggests that innovation is driven by market demand. Research and development activities are focused on meeting specific market needs with new products (Sheffer, 2011)

In the construction industry, the technology-push and market-pull dynamics can be observed through an example. For instance, a construction company that invests in research and development to create an innovative building material represents the technology-push approach.

They develop the material first and then market it to generate demand, believing that the market will eventually recognize the value of their innovation.

In contrast, another construction company that closely monitors market trends and identifies a growing demand for sustainable buildings represents the market-pull approach. They conduct research and development activities to meet the specific market need, focusing on developing a construction method that aligns with sustainability requirements.

These examples demonstrate how construction companies can approach innovation either by internally driving RandD efforts or by responding to explicit market demand. Both approaches have the potential to lead to successful innovations in the construction industry.

Innovation diffusion in the construction industry

A particular research area delves into the intricacies of innovation diffusion in the construction sector (Henderson and Clark, 1990). For new knowledge and technical solutions to evolve into innovations, they must be compatible with and be able to adjust to pre-existing products, systems, and organizational solutions. Innovations can be categorized by their influence on the existing supply chain, the design and construction procedure, or the parties involved (Hall et al., 2018). A distinction is drawn between innovations that instigate alterations in product components and those that modify the interconnections between components. Consequently, there are four categories of innovations: incremental, modular, systemic, and radical (Bygballe, Endresen and Fålun, 2018).

Incremental and modular (*not* modular construction) innovations work well with the way jobs are divided and specialized already. Incremental innovations are small, ongoing changes, such as making machines use less energy (Hall, et al., 2018). Modular innovations, however, are about changing parts of a product without changing the whole design, such as using energy-saving LED bulbs in current light fixtures (Sheffer, 2015).

Contrarily, systemic and radical innovations not only augment the total functionality of the product but also redefine the delineations between work divisions traditionally carried out by each firm in the supply chain. Such systemic innovations necessitate a collective shift in the design, prefab, and/or assembly practices by various companies within the supply chain network. They modify the connections between modules or overhaul the overall system design, as exemplified by floor heating and intelligent building management systems (Sheffer, 2015).

Radical innovations lead to fundamental changes in products, processes, or business models, having the potential to disrupt existing markets and create new ones, such as modular construction or timber construction (Hall et al., 2018). Systemic innovations, which change how work is done across different professions and trades, spread up to three times slower than modular innovations that work well with the existing supply chain (Sheffer, 2015)

The Table 5 below provides a concise overview of different innovation forms and their influence on the supply chain. The impact on the chain varies depending on the specific context and circumstances of each situation.

Table 5: Innovation classification

Form of Innovation	Description	Impact on the Supply Chain
Incremental	Small, continuous improvements to existing products or processes	Minimal disruption, easy adoption
Modular	Changes to individual components without altering the overall architecture	Limited disruption, fits within existing structures
Systemic	Large changes requiring adjustments in multiple system parts	Significant coordination and adaptation required
Radical	Fundamental changes that redefine the basis of a product, process, or industry	Major disruption, may eliminate existing structures

Fragmentation and Integration in the Construction Industry

The construction industry is widely recognized for its complexity and fragmentation (Fergusson, 1993). This section aims to expound on this issue, focusing on the industry's structure, decentralized project nature, and their impacts on systemic innovation diffusion.

Fragmented Structure

A single firm cannot hardly independently realize systemic innovation, largely due to the industry's interorganizational nature (Taylor, 2005). The industry's structure is characterized by networks of interconnected product and process investments that generate a complex web of interdependent solutions. Such a network system complicates the integration of new solutions that originate outside the established infrastructure (Bygballe et al., 2018).

This industry structure has a substantial influence on the systemic innovation adoption rate. According to Sackey et al. (2015), project organizations are forms of socio-technical systems, and the adoption of systemic innovation necessitates negotiation among multiple actors and firms involved (Winch, 1998).

The construction industry is heavily divided in three ways: horizontally, vertically, and over time, or longitudinally (Fergusson, 1993).

- Horizontal division happens because each part of a project is bid on separately in a highly competitive environment. This is typical for traditional project deliveries. An example of this would be lump-sum bids, where clients often go with the lowest bidder who still meets their needs. These bidders then ask for bids from various specialized subcontractors. These steps happen one after another and aren't coordinated, which leads to custom-made products and a lack of efficiency (Hall et al., 2018)
- Vertical division takes place because each phase of a project needs different people, decision-makers, and priorities. This separation of stages can lead to people acting in their own interest and passing costs onto others in later stages (Hall et al., 2018).
- Longitudinal division, or division over time, happens when project teams break up after a project ends and are chosen for new projects based on competitive bidding (Taylor and Levitt, 2005).

Combined, these three types of division lead to large costs in all infrastructure projects. It also means work on-site is split up a lot, especially among subcontractors.

Impact of Fragmentation on Innovation

The fragmented structure of the construction industry influences the organization of substantial construction projects, transforming them into decentralized modular clusters (Sheffer, 2011). Vertical fragmentation leads to the role of the systems integrator being shared between two vastly dissimilar entities: the general contractor and the chief architect (Winch, 1998). This divergence impedes efficient performance of essential roles for innovation success, such as mediation and championing (Winch, 1998; Hall et al, 2020)

The majority of project operations are regulated via standardization and craft management. This operational approach, in combination with the general contractor's weak system integration role, facilitates the design, coordination, and construction of independent project pieces with minimal system integration necessary (Hall et al., 2020)

Within this environment of decentralized modular clusters, main building contractors often do not possess the overhead cost structure or capacity required to orchestrate systemic innovations (Hall et al., 2020). Systemic innovations, demanding considerable changes in design interfaces and installation procedures, are frequently bypassed in favor of localized product innovations.

The fragmented and decentralized modular cluster structure of the construction industry is ill-suited to recognizing and adopting innovative threats (Utterback, 1994). This structure buttresses the resistance of industry participants, who are inclined to strengthen their footholds in older products.

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Supply chain integration practices

The Construction Industry has seen a rise in efforts to integrate resources and align objectives across company boundaries, thus promoting the adoption of systemic innovations in projects (Sheffer, 2011). This integration is primarily realized through Supply Chain Practices and Integration (SCPIs), an area that has increasingly caught the attention of CI organizations and scholars alike. This chapter aims to unpack the concept of SCPIs and its significance in fostering innovation diffusion in the Construction industry (Hall, et al, 2018)

SCPIs are project-wide practices designed to organize information, processes, people, and firms for the purpose of collaboration and integration within the supply chain (Ashcraft, 2012). They can range from building information modeling (BIM) coordination, multiparty contracts, early involvement of key participants, liability waivers among key participants, to team co-location and more (Hall, et al, 2018).

The integration of supply chains in the construction industry can be conceptualized along the three dimensions of fragmentation (Levitt and Sheffer, 2011). According to Hall et al. (2018) can the implementation of SCPIs "enhance mechanisms of collaboration, coordination, information exchange, shared understanding, and cooperation" consequently amplifying project integration (Sackey et al., 2015). Furthermore, SCPIs can significantly impact inter- and intra-organizational relations within the construction supply chain, thus affecting innovation adoption rates (Papadonikolaki and Wamelink, 2017).

SCPIs utilize both formal and informal mechanisms (see also next section on mechanisms) to function effectively (Bygballe et al., 2015). Formal methods are usually protected and implemented through the practices of contractual agreements and organizational structures. In contrast, informal methods rely on practices that uphold norms, routines, and values, encompassing social processes and relationship dynamics (Hall, et al., 2018).

In summary, SCPIs play a pivotal role in the construction industry. Their implementation aids in the integration of the supply chain, fostering the environment necessary for innovation diffusion. Understanding and implementing SCPIs correctly, therefore, is crucial for construction organizations aiming to optimize their innovation adoption rate and enhance their overall productivity and performance.

Traditional project organisation

The construction sector, due to its fragmented structure, organizes large-scale projects as 'decentralized modular clusters' (Sheffer, 2011). The role of systems integration is bifurcated by the industry's vertical fragmentation, with the primary contractor and the principal designer each bearing a share of the responsibility (Winch, 1998). This split can hamper the effective execution of roles crucial to successful innovation, such as mediation and advocacy (Winch, 1998). The majority of project activities are governed by standardization (Garud, Kumaraswamy, Langlois, 2009). The industry's adherence to conventional product structures and design guidelines helps ensure compatibility across components produced by different firms (Langolis and Robertson, 2009; Sheffer, 2011; Hall, 2018). Figure 12 illustrates this decentralized modular cluster.

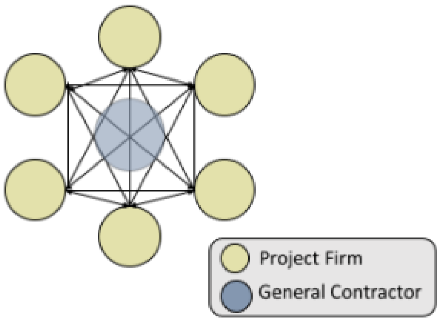


Figure 12: Decentralized modular clusters (adopted from Sheffer, 2011)

In the end, the general contractor operates as a relatively weak systems integrator, allowing for standard tasks to be designed, coordinated, and executed as independent segments with little system integration needed. Unlike primary contractors in automobile or airplane manufacturing, the main contractor in construction often functions more as a negotiator for subcontractor services rather than as a systems integrator, especially on smaller-scale tasks. In a decentralized modular environment, primary building contractors typically do not have the necessary overhead cost structure or the ability to facilitate systemic innovations (Hall, 2018).

Mirroring hypothesis

In studies of organizational design and strategy, the "mirroring hypothesis" proposes that an organization's structure should ideally match the architecture of its technical systems. This alignment is seen as a solution to the challenges that arise from managing complex, interconnected tasks (Colfer and Baldwin, 2016). Simply put, the hypothesis suggests that the internal relationships within an organization or project should reflect the complexity of the tasks they carry out.

However, the mirroring hypothesis doesn't explicitly determine the direction of causality. Some scholars suggest that technical complexities might shape organizational connections. Sanchez and Mahoney (1996), for instance, argue that products could potentially design organizations because the coordination tasks inherent in specific designs largely determine the feasible organizational designs for their development and production. This is echoed in Conway's Law, which suggests that organizations tend to create designs that mimic their own communication structures (Conway, 1968).

The basis of the mirroring hypothesis lies in product modularity and information concealment (Baldwin and Clark, 2000). Modularity refers to the ability of a system to be divided into smaller units or modules that can be arranged in different ways. On the other hand, modularization is the process of making a complex system more modular (Hall, 2018). These concepts allow for the management of complexity through the concealment of information, whereby each module in a technical system is informationally isolated from others according to a set of design rules. This allows separate entities, teams, or firms to work independently on different modules while ensuring the functionality of the overall system (Colfer and Baldwin, 2016). Therefore, systems with many technical interdependencies require tightly connected organizations, while individual modules can be managed by loosely connected firms (Hall, 2018)

Mirroring Trap

Colfer and Baldwin (2016) undertook an in-depth study of the mirroring hypothesis and established a link between technical interdependencies and organizational structures. However, they also identified a 'mirroring trap’ where organizations could miss out on restructuring opportunities due to over-segmentation of tasks and expertise, referred to as ‘strict mirroring'. Excessive reliance on rigid mirroring may impede recognizing cross-boundary innovations. Over time, organizations can become entrenched in component-level activities, reducing their systemic innovation capability (Henderson and Clark, 1990; Utterback, 1996). Although efficient in the short term, rigid mirroring can become a trap during rapid technological changes. The Architecture, Engineering, and Construction (AEC) industry is cited as an example of an industry caught in this 'mirroring trap', missing out on new technical architecture opportunities (Colfer and Baldwin, 2016).

Partial mirroring

Partial mirroring refers to a strategy in which organizations consciously strive to understand technologies beyond their specific task boundaries (Hall, 2018). This approach often comes into play during times of technological disruption, when companies adhering strictly to the "mirroring hypothesis" might struggle to identify innovations that are beneficial but do not fit within the existing industry structure.

Under these circumstances, companies can overcome these challenges by proactively exploring emerging technologies and existing contract arrangements. They aim to identify "bottlenecks" that could be addressed by changing technical dependencies and organizational connections. This process can lead to the formation of new institutional arrangements and ultimately provides a competitive advantage in technically dynamic industries (Colfer and Baldwin, 2016; Cacciatori and Jacobides, 2005).

This strategy of partial mirroring is particularly relevant to system integrators - firms responsible for overseeing the operation and evolution of a complete technical system and its associated supplier network. As technology evolves rapidly and systems become increasingly complex, these system integrators need to have a broad and deep understanding that goes beyond the tasks they perform in-house. They must continuously develop competencies across a wide range of technical fields, with their knowledge base extending beyond the confines of their specific tasks (Colfer and Baldwin, 2016; Hall, et al. 2020).

Strategic Mirror-breaking

Strategic Mirror-breaking is a method that businesses use to manage increasing technical change and complexity. In this strategy, a firm might decide to "break the mirror" of its current structure in two ways: through relational contracts or preemptive modularization.

Relational contracts are long-term agreements that promote communication and collaboration across organizational boundaries, helping to manage complex interdependencies between different parts of a company. This strategy focuses on creating long-lasting, mutually beneficial relationships to manage complexity (Colfer and Baldwin, 2016).

Preemptive modularization is when a company redesigns its structure to create new, modular technical architectures within its organization. This approach can allow a firm to drive significant, architectural, and radical innovations, even when technology is rapidly changing (Baldwin and Clark, 2000; Henderson and Clark, 1990). While it may run the risk of rushing development and overlooking some interdependencies, it could also give a firm a competitive edge by staying ahead of technical changes.

In cases where a product is more digital than physical, firms might use pre-emptive modularization to convert products into platforms (Hall, et al. 2018). This allows them to use different degrees of modularity, interdependence, and complexity in different parts of their system, which can make collaboration between different parts of the organization more effective (Colfer and Baldwin, 2016).

Emerging organisation structures for modular construction

This section delves into the five new trends for restructuring efforts in the AEC sector, as pinpointed by Hall (2018), Lessing (2019), and Hall et al. (2022). We'll examine current restructuring tendencies, explore how they relate to the mirroring hypothesis, outline their potential advantages and challenges, and illustrate these points with examples from the contemporary industry landscape.

collaborative modular clusters

Architects, general contractors, and other systems integrators in the construction industry are increasingly embracing supply chain integration practices (SCIPs) to facilitate collaboration across projects (Bygballe et al., 2014; Hall et al., 2018). SCIPs aim to promote alignment and coordination of information, processes, and personnel throughout the entire supply chain (Hall et al., 2018). Notable examples of SCIPs include initiatives such as building information modeling (BIM) coordination, the implementation of the last planner system, and the practice of team co-location.

The adoption of SCIPs helps to shift the industry from a decentralized modular cluster approach to a more collaborative modular cluster framework, enabling informal integration without significant structural changes. For instance, the practice of team co-location, where team members physically work in proximity, enhances coordination, communication, and trust among project participants. Although SCIPs require investment in resources, they also present opportunities to identify and gradually adopt new interdependencies for future projects. This allows for a more cohesive and efficient workflow across the supply chain, promoting better project outcomes (Hall et al., 2022).

virtual project-based companies

Over the past decade, relational contracting methods such as Integrated Project Delivery (IPD) and Project Alliancing have gained popularity in the construction industry (Hall, et al. 2018; Lessing, 2019). These approaches not only incorporate SCIPs but also introduce formalization through a multi-party relational contract, aligning up to 17 firms to collectively share the financial risks and rewards of a project. This effectively creates a "virtual, project-centric organization" (Thomsen et al., 2009), where individuals remain employees of their respective firms but take on roles based on their skills and project needs rather than their employers' business nature.

This structure promotes vertical integration, bringing together project sponsors, designers, general contractors, and trade contractors, as well as horizontal integration among traditionally separate trade contractors and system designers. Such comprehensive integration facilitates the co-creation of technical interdependencies and systemic innovations within a cooperative relationship (Hall et al., 2018; Lavikka et al., 2017). Recent research suggests that project alliancing enables firms to supplement modular designs with SCIPs, which in turn enhance collaboration (Tee et al., 2018). Moreover, IPD has been found to enhance trust and communication, vital elements for the success of these collaborative relationships (Pishdad-Bozorgi and Beliveau, 2016).

However, it should be noted that the concept of IPD teams persisting across multiple projects and functioning as a highly efficient unit has not been conclusively proven. This suggests that project-based organizations still face challenges related to fragmentation once a project is completed. Further research is needed to explore and address these issues to fully leverage the benefits of relational contracting methods in the construction industry.

Integrated hierarchical firms

Industrialized construction firms, particularly those specializing in modular construction, are undergoing a significant transformation towards an integrated hierarchical structure. This approach enables these firms to maintain control over crucial aspects of their operations, including product architecture, processes, and various stages of production (Lessing, 2006; 2015).

In the context of modular construction, an integrated hierarchical firm retains control over the entire production chain within its organizational structure, from design to assembly. This encompasses essential activities such as design, manufacturing, transport, and on-site assembly, all of which are coordinated within the firm's unified structure (Johnsson, 2011).

This integrated structure provides a foundation for adopting a comprehensive approach to modular construction, emphasizing streamlined processes, efficiency, and quality control. By keeping these core functions in-house, these firms are better positioned to address the unique demands of modular construction, enabling them to develop and refine innovative solutions (Lessing, 2015).

Ultimately, integrated hierarchical firms in the modular construction industry leverage their internal control over processes and operations to ensure effective management and coordination. This drives innovation and enhances the overall quality of their products. The integrated structure plays a vital role in navigating the complexities and specific requirements of modular construction (Johnsson, 2011).

core-periphery platform structures

Core-periphery platform structures in industrialized construction serve as key models for modular construction efforts. Within this framework, 'core' firms utilize digital systems to design and oversee modular architecture without engaging in direct production (Colfer and Baldwin, 2016).

The core firms capitalize on digital platforms to devise the configuration of modular projects, which are produced by 'periphery' partners specializing in diverse sectors such as manufacturing and engineering (Lasi et al., 2014). This approach facilitates an effective amalgamation of design and manufacturing elements crucial to modular construction - a process characterized by prefabricated, repeatable, and interchangeable units.

Emphasizing 'Industry 4.0' principles, these core firms engage in mass-customization of modular parts, providing a flexible and efficient construction approach that can cater to unique customer needs while benefiting from the economies of scale (Lasi et al., 2014).

In this structure, the continuity of modular product development and improvement is maintained through the core firms' digital platforms. The platforms enable longitudinal integration, tracking, and standardization of modular parts across multiple projects, thereby enhancing their reusability and reducing wastage (Colfer and Baldwin, 2016).

However, the architecture of the modular product, though flexible, is restricted by the options available within the core firm's platform. Furthermore, as the control over the modular product design isn't entirely within the core firm, innovation requires a longer-term collaboration with periphery partners (Colfer and Baldwin, 2016). A notable example of this structure within modular construction is Project Frog, which employs a cloud-based platform for architects to design with their proposed modular system (Hall et al, 2020). Their process is a testimony to the potential of digital tools in streamlining and optimizing the modular construction process (Hall et al, 2022)

Spinn off factory

The concept of a "spinoff" factory or spinoff firm refers to the creation of a new business line or factory that emerges from an existing project-based firm (Colfer and Baldwin, 2016). This strategic move allows project-based companies to transition towards a more industrialized construction approach, integrating aspects of off-site manufacturing and modular construction. However, it is important to note that there is limited literature specifically exploring spinoff factories within the construction industry.

The establishment of a spinoff factory provides an opportunity for project-based firms to develop a learning relationship between project demands and the need for longitudinal continuity in a factory environment. By setting up a dedicated facility or business line, the firm can optimize efficiency, streamline production processes, and enhance quality control (Colfer and Baldwin, 2016). This transition toward industrialization enables the firm to capitalize on the benefits of off-site manufacturing, prefabrication, and modular construction, which are key drivers of improved productivity and cost-effectiveness in the construction industry (Lessing, 2006; 2015).

However, one significant challenge associated with spinoff factories is the continuous need to update and educate the existing supply chain about the capabilities and requirements of the new factory. This includes ensuring effective coordination and collaboration between the spinoff factory and the existing project-based firm, as well as managing the transfer of knowledge and expertise across the organization (Colfer and Baldwin, 2016). This aspect highlights the importance of fostering effective communication channels and promoting a culture of knowledge sharing within the company.

An example of a spinoff factory in the construction industry is Digital Building Components, which emerged from the general contractor DPR Construction (Colfer and Baldwin, 2016). This spinoff factory specializes in digital manufacturing and off-site construction components, leveraging technology and automation to enhance productivity and efficiency in the construction process. While this example demonstrates the potential of spinoff factories in driving industrialization within the construction industry, it also underscores the need for further research and exploration in this area.

It is worth noting that the literature on spinoff factories within the construction industry is relatively limited, and further investigation is required to gain a deeper understanding of their implementation, challenges, and potential benefits. Nonetheless, the concept of spinoff factories holds promise as a strategic avenue for project-based firms seeking to embrace industrialized construction principles and optimize their operations in an increasingly competitive market.

Definition: Real estate developer

A project developer's primary objective is to generate profits through the development of diverse real estate properties, ensuring the long-term viability of their company. These properties encompass residential buildings, office spaces, commercial premises, recreational real estate, or a combination thereof (Huisman, 2004). Nozeman and Fokkema (2008, p. 15) provide a categorization of project developers into five distinct types, each characterized by different goals and project portfolios. These categories are as follows:

1. Independent developer: Independent developers focus exclusively on real estate development and do not have any affiliated entities.
2. Developer associated with a construction company: This category emerges when construction companies intentionally acquire property as a means of expanding their core business activities. The level of integration between development and construction functions can vary, with some developers entrusting the actual construction work to external parties. The acquisition of land allows these contractors to create favorable conditions for future development operations (Huisman, 2004).
3. Developer affiliated with an institutional investor: Institutional investors view real estate as an attractive asset class. They may engage in direct property development, exerting substantial control over the content and quality of their property portfolios, and realizing development profits. Alternatively, they may opt to delegate the construction activities to third-party developers. While institutional investors have traditionally focused on retail and office markets, there is a growing trend of residential investment due to the appealing yield (Huisman, 2004).
4. Developer affiliated with a financial institution: Financial institutions employ project development as a strategic tool to enhance their funding activities and overall revenue. Additionally, it serves as a means to ensure the continuity of their business operations. Developers associated with banks, for instance, seek to expand their parent company's mortgage portfolio while maintaining their independent organizational structure (Huisman, 2004).
5. Developers affiliated with a housing corporation: Housing associations primarily aim to provide affordable housing for the general public. In the Netherlands, housing associations possess the largest social housing stock in Europe, accounting for 29% of the total housing stock. However, housing associations assume a less prominent role as developers. Since the enactment of the Housing Act in 2015, housing associations are restricted from engaging in activities beyond those serving the general Economic Interest (SGEI). SGEIs are services that the state provides to the public when market forces alone are insufficient (EU, 2015). Consequently, housing corporations predominantly function as clients of contractors and project developers.

The diagram (Figure 13) presents a visual representation of the project developer's position within the development market. The diagram serves as a preliminary illustration of the landscape in which the developer operates, emphasizing their central role in area development and their close connection with the surrounding environment. It highlights the collaborative nature of development, with various stakeholders contributing to the overall process. This visual representation provides a framework for better comprehending the diverse roles assumed by different types of developers within this context. For instance, the financial markets are represented as sources of investment and funding for developers, while the building sector introduces the concept of the builder developer in area development. The project developer, positioned at the centre of this landscape, activities to create real estate within this multifaceted and dynamic environment.

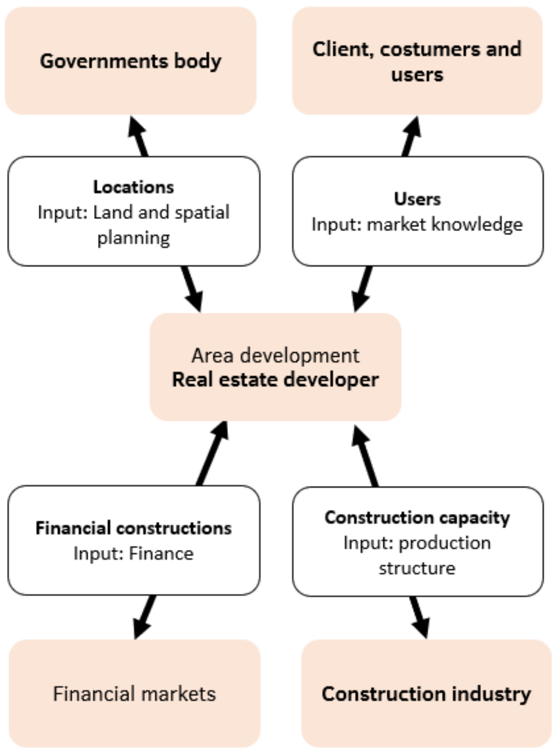


Figure 13: Positioning of the real estate developer

Mechanisms by real estate developers

This chapter examines real estate developers' mechanisms, including formal and informal approaches, and their importance for systemic innovation. It explores Business Model Innovation (BMI) in real estate, focusing on Industrialized Construction, demonstrating its role in market adaptation and competitiveness. It emphasizes the need for alignment among business mechanisms for successful innovation.

Comprehension of Mechanisms

The understanding of mechanisms is essential for understanding how different elements work together to achieve specific outcomes. Mechanisms can be categorized into formal and informal types (Bygballe et al., 2015), and their understanding has implications for organizational outcomes such as knowledge sharing, exploration, and offering. This chapter provides an overview of the concept of mechanisms, their categorization, and their impact on organizational processes.

Mechanisms refer to the coordinated activities of distinct elements that lead to a specific output. According to Glennan, Illari, and Weber (2021), a mechanism (Y) facilitates the achievement of a particular outcome (X) through its functioning. For example, modular construction serves as an illustration of this concept, where separate modules are constructed individually and then assembled on-site to achieve the final desired construction outcome.

Formal and Informal Integration Mechanisms

Prior literature has highlighted the differentiation between formal and informal integration mechanisms and their impact on organizational outcomes. Formal mechanisms are documented and controlled through contractual agreements and organizational practices, while informal mechanisms encompass norms, routines, and values. Bygballe et al. (2015) emphasize that both formal and informal mechanisms are crucial in complex projects like modular construction, where their interaction plays a significant role in achieving project success. Tsai (2002) and Jansen et al. (2006) have shown that both types of mechanisms have distinct effects on knowledge sharing, exploration, and offering. According to Zahra and George (2002), informal mechanisms play a valuable role in facilitating idea exchange, while formal mechanisms are characterized by a more systematic approach. Informal mechanisms are associated with exploratory learning, which involves the exploration of new ideas and knowledge. On the other hand, formal mechanisms tend to foster exploitative learning outcomes, which focus on refining and leveraging existing knowledge (Daft and Lengel, 1986; Zahra and George, 2002). It is important to consider both formal and informal integration mechanisms to achieve a balanced approach.

Mechanisms and Systemic Innovation Adoption

Systemic innovation adoption is a complex process, as show in previous section, influenced by various factors, including shared routines, norms, and processes (Alin et al., 2013). Achieving a balance between formal and informal mechanisms is critical for successful systemic innovation (Sackey et al., 2015; hall et al.,2018). Informal information exchange and social interactions within interdisciplinary teams contribute to collective knowledge, trust, and momentum during the innovation process (Plesner and Horst, 2013). Local owner representation and financial flexibility are also key factors for effective system integration in project-based supply chains (Winch, 1998; Papadonikolaki et al., 2016; Papadonikolaki and Wamelink, 2017).

Both formal and informal mechanisms can address fragmentation within the industry structure and facilitate vertical and horizontal integration (Fergusson, 1993; Hall et al., 2018). However, achieving long-term supply chain integration remains challenging due to the unique nature of large and complex projects. It is important to distinguish between mechanisms and Supply Chain Integration Practices (SCIPs) as each project employs a distinct set of SCIPs. Understanding the underlying mechanisms of SCIPs provides a nuanced perspective on achieving supply chain integration (Franz et al., 2016). Table 6 provides a comparison between formal and informal mechanisms based on various attributes, including documentation, control, contractual nature, organizational aspects, flexibility, knowledge exchange, implementation, nature, and decision-making based on the literature in this section.

In conclusion, the comprehension of mechanisms is vital for understanding how different elements work together to achieve specific outcomes. Formal and informal integration mechanisms play distinct roles in organizational processes, impacting knowledge sharing, exploration, and venturing. Achieving a balance between these mechanisms is crucial for systemic innovation adoption.

Table 6: distinction between formal and informal mechanisms (informed by Bygballe et al. (2015), Zahra and George (2002) and Hall et al. (2018)

Mechanism Attribute	**Formal**	**Informal**
Documentation	Documented	Not documented
Control	Controlled	Not controlled
Contractual	Yes	No
Organizational	Systematic	Normative
Flexibility	Less flexible	More flexible
Knowledge Exchange	Systematic	Informal
Implementation	Planned	Emergent
Nature	Structured	Adaptive
Decision-making	Formal	Informal

Business Model Innovation

The concept of business models has attracted significant scholarly attention in recent years, with researchers exploring various aspects of this theoretical framework (Lessing, 2019). However, there is no consensus among academics regarding a precise definition of a business model (Zott et al., 2011). A business model, within this context, refers to the way a company integrates its essential components and operations to provide value to customers. It involves the interconnectedness of these components throughout the organization, including the supply chain and stakeholders, in order to create value through interdependent networks (Brege et al., 2014). To enhance the understanding of business models within the context of Industrialized Construction (IC), Brege et al. (2014) propose three essential constituents: the operational platform, the market position, and the offering.

To differentiate between Industrialized Construction and traditional construction business models, this study refers to the business model classification presented by Lindgardt et al. (2009). This classification categorizes business models into two interconnected facets, consisting of six foundational principles (see Figure 14). According to Lindgardt et al. (2009), business model innovation (BMI) can be divided into two categories: the customer-oriented aspect of the value proposition and the operational model that supports it.

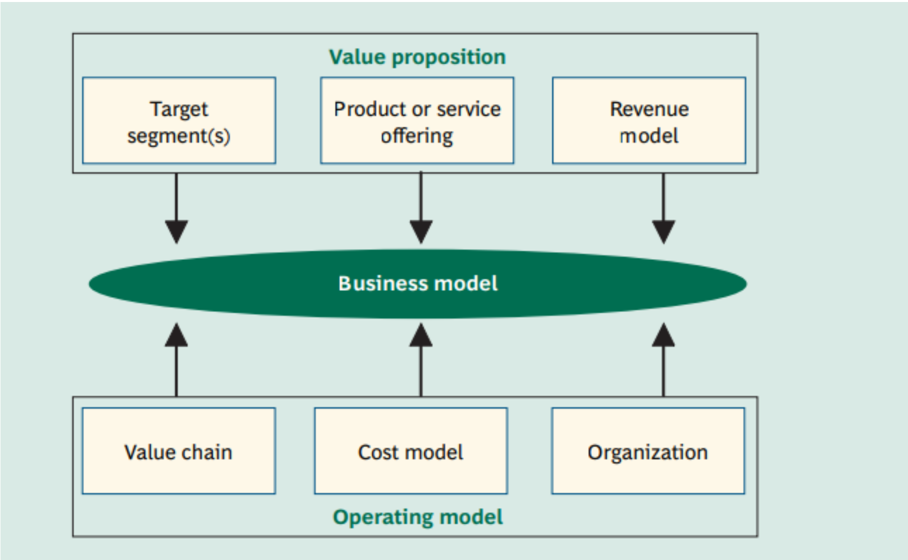


Figure 14: Business model innovation (Adopted from Lindgardt et al., 2009)

One critical aspect where BMI can provide substantial insight into the mechanisms employed by real estate developers is through its systemic perspective. Real estate developers operate within a complex system, interacting with various stakeholders such as investors, clients, government agencies, suppliers, etc. Therefore, the systemic perspective of BMI can be instrumental in analyzing and understanding these relationships. This insight can enable developers to identify potential improvements in their business model and adapt to market changes (Magretta, 2002).

Furthermore, the inherent emphasis of BMI on adaptability in response to external changes can be particularly beneficial in the real estate sector, which often faces economic fluctuations, regulatory changes, and evolving customer preferences. Real estate developers can leverage BMI to respond effectively to these changes, enhancing their competitiveness and long-term sustainability (Teece, 2010).

The context of Industrialized Construction brings forth another angle. The shift to industrialized processes and technologies has led to several approaches and strategies, challenging the traditional construction models. By applying BMI, developers can critically evaluate their current operational model and value proposition against IC business models. This comparison can help developers find opportunities for innovation and stay competitive in a rapidly changing construction industry (Lindgardt et al., 2009).

In summary, Business Model Innovation provides a valuable perspective for real estate developers to gain insight into their operational mechanisms. It fosters adaptability to market changes and encourages critical evaluation, which can promote innovation and competitiveness. Nonetheless, it requires real estate developers to maintain an open mindset and be proactive in analyzing and modifying their business models to leverage its benefits fully.

Business Model Innovation and Mechanisms

Business Model Innovation (BMI) is a process where a company adjusts or changes its way of doing business to create, deliver, and capture value in response to changes in the market or other external factors (Lindgardt et al., 2009). The mechanisms, in this context, refer to the various components of a business model - products or services, target customers, distribution channels, supply chain, cost structure, and revenue streams, among others. Understanding these mechanisms is crucial for a successful business model innovation.

A business model is a systemic configuration of these mechanisms, and they are interdependent. Therefore, the innovation or change in one mechanism (e.g., introducing a new technology in the supply chain) will likely affect other mechanisms (e.g., cost structure, product delivery) in the business model (Magretta, 2002).

Each mechanism can be seen as a device for innovation. By reconfiguring these mechanisms, businesses can explore new ways of creating and delivering value to their customers, often resulting in a competitive advantage (Lindgardt et al., 2009). For instance, companies may decide to serve a new target customer segment, offer different products or services, utilize new distribution channels, or change their revenue structure as part of their business model innovation.

Alignment between the mechanisms is also essential for the success of BMI. For example, a company aiming to serve a high-end market segment (target customer mechanism) must ensure its product offering, distribution channels, and revenue structure align with this strategy.

In conclusion, the relationship between BMI and mechanisms is symbiotic. The understanding of mechanisms provides insight into how a company can innovate its business model, while the process of BMI can lead to a better understanding of these mechanisms and their interdependencies.

Figure 15 presents a conceptual comparison of the business models of project-based, hybrid-based, and product-based approaches. This comparison is set within the context of various modular construction concepts, strategies, and mechanisms, as outlined in the preceding sections of this theoretical framework.

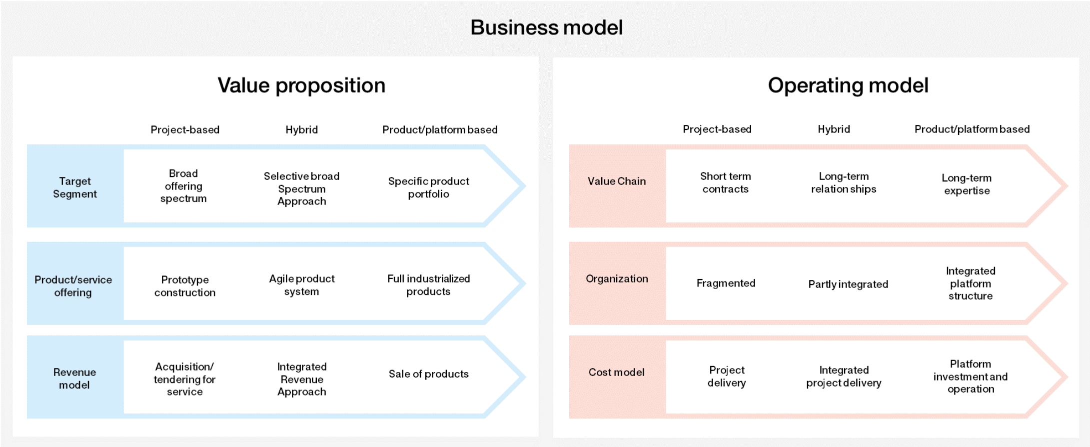


Figure 15 : Framework of project, hybrid, and product- based approaches

3

Methodology and Method

Research Objectives and Deliverables

This thesis is centred around a key question that aims to explore the intersection of real estate development and the integration of modular construction techniques. The primary objective of this research is to bridge the gap in literature by studying the role of project developers in integrating modular construction into their business practices. This objective is approached with a focus on the real estate sector, exploring the challenges and drivers, integration strategies, and the mechanisms employed for the integration. Specifically, the research objectives are as follows:

1. Analyse integration strategies that real estate developers employ to mitigate the challenges identified.
2. Investigate the specific mechanisms (tools, resources, partnerships) that real estate developers can utilize in these integration strategies.
3. Identify the primary challenges and drivers faced by real estate developers in integrating modular construction in their businesses.

Each of these objectives corresponds directly to a sub-question of the research, aiming to provide a comprehensive understanding of the process of integrating modular construction in the real estate sector.

The following are the expected deliverables from this research:

1. Comprehensive Literature Review and frame of reference: An in-depth review of existing literature on modular construction and its intersection with real estate development, focusing on challenges, drivers, integration strategies and mechanisms.
2. Empirical Data: Collection of empirical data from interviews with experts in the field to obtain first-hand insights on the integration process, challenges, drivers, and strategies in the real estate sector.
3. Analysis and Synthesis: Analysis of the data collected and synthesis of insights on how real estate developers integrate modular construction within their business. Identification of the primary challenges and drivers, effective integration strategies, and potential mechanisms to implement these strategies.
4. Recommendations: Based on the findings, the research will provide actionable recommendations for real estate developers and other stakeholders for effective integration of modular construction.

The proposed deliverables will provide both academic and practical value, contributing to the existing body of knowledge on modular construction in the real estate sector and offering actionable insights for industry practitioners.

Research Approach

Methodology

In the realm of Construction Management and Economics, a clear distinction is drawn between methodology and method (Chan, 2020). While the method is the practical aspect of data collection and analysis, the methodology gives the theoretical foundation that informs and justifies these practical actions. The methodology is the roadmap, explaining why the research has taken the path it has, and the method is the vehicle, detailing the actual steps taken in the journey (Chan, 2020).

For this study, the chosen roadmap is a balanced approach, making it possible for empirical data and theoretical foundation to reinforce and inform each other (called abductive reasoning). On one side, it has the principles of deductive reasoning - this is where you start with an established theory and then gather data to support or challenge it. On the other side, it leans on inductive reasoning, which is the process of observing facts and then forming a theory based on those observations. (Timmermans and Tavory, 2012; Chan 2020).

Abductive reasoning combines these two worlds. It involves moving back and forth between collected data (the practical observations of the real world) and theoretical insight (our understanding based on previous knowledge). In this way, the understanding of the topic is not static but continually informed and refined by new data. This dynamic and flexible approach is beneficial when dealing with intricate, real-world scenarios.

In this research, it has proven especially helpful in exploring how real estate developers incorporate modular construction into their businesses. As more information was gathered and more theories were tested, the research's insights where constantly evaluated. This is the essence of abductive reasoning and why it has been selected as the methodology for this study.

The "hourglass" model as presented by Chan (2020) has been a guiding light for structuring this research. This model emphasizes the importance of clarity, coherence, and comprehensiveness in academic writing, and assists in organizing and presenting research content effectively. Figure 16 represents the hourglass model as used for this study. In the front-end, we move from general to specific: we begin with a wide context, identify gaps in the existing literature, and progressively narrow down to our specific research question. The back-end then mirrors this process, but in reverse. We start from the specific findings of the study, interpret their meanings, and expand to discuss their broader implications, returning to the wider context. The iterative process between the front-end and back-end of the study relates to the chosen research methodology.

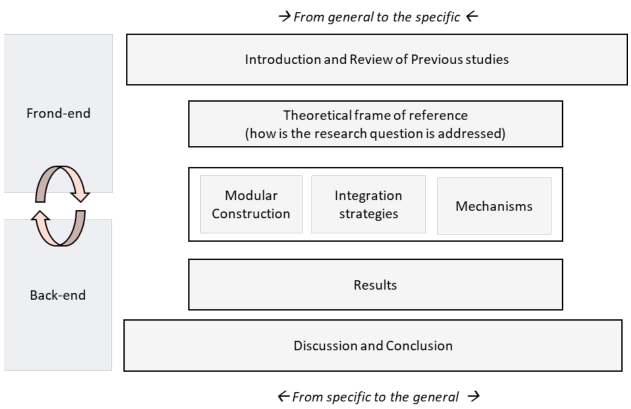


Figure 16: Logic of the research (inspired by Chan, 2020)

Research method and design

While formulating the methodological approach for this research, the framework is divided into both front-end and back-end processes, detailed in four principal components: the review of previous studies, the theoretical frame of reference, empirical research, and ultimately, the discussion and conclusion.

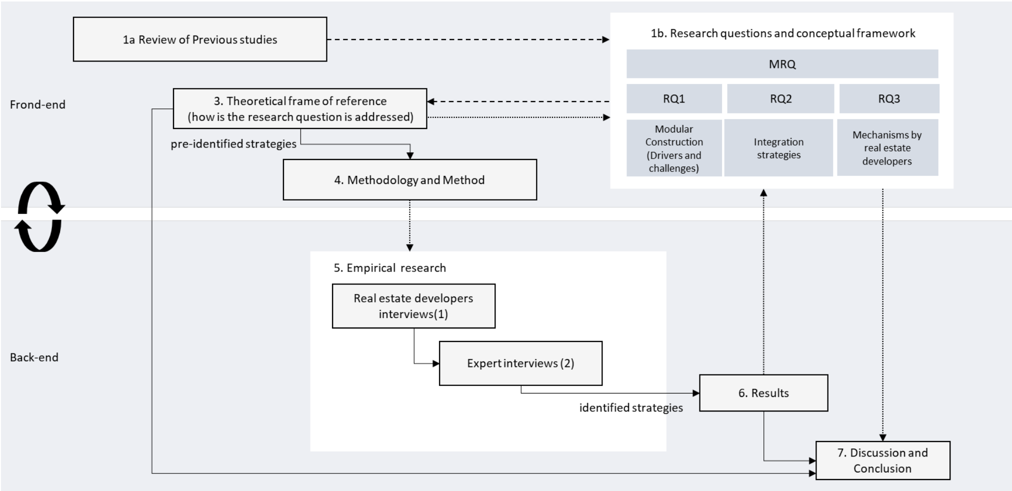


Figure 17: Research design; numbering is corresponding with the chapters of this thesis.

The research process initiates with a comprehensive review of previous studies, a crucial stage that lays the foundation for the research questions and the conceptual framework as shown in the introduction. The research direction is set by defining the primary focus - the integration of modular construction within real estate development. This focus is subsequently justified, providing rationale as to why this topic demands attention. The process proceeds with a thorough examination of extant studies and an articulation of the gap in the current body of knowledge. A understanding of what is known and unknown about the research focus is essential, leading to the formulation of a 'burning question' that merits attention.

Following the review, the research delves into establishing a theoretical frame of reference. This part elucidates and offers perspectives on central concepts, including modular construction, paradigms associated with industrialized construction, and the integration strategies and mechanisms employed by real estate developers.

This theoretical review's data collection significantly relies on academic search engines such as Google Scholar, in addition to the digital platform of the TU Delft Library. Books and commercial publications also contribute to shaping the theoretical background. Research papers that possess significant scholarly rigor and receive frequent citations are given priority. However, due to the innovative nature of the subject in the construction industry, less-cited studies are also considered.

The research then transitions into the empirical phase, where qualitative data, informed by the theoretical framework, is collected. This stage provides a basis for evaluating the strategies proposed by the interviewees. The empirical research initiates with interviews from eight experts, followed by a verification process involving two additional experts to validate the previously identified strategies. The criteria for selecting these experts have been carefully formulated and are detailed subsequently. The outcomes from these interviews are then collated into the results section, where the strategies are categorized and compared using a cross-analysis.

Finally, the research concludes with the discussion and conclusion stage, where the findings are interpreted against the backdrop of existing literature. This phase presents the fresh insights derived from this research and discusses how it challenges current discourses within Construction Management and Economics and beyond. The research findings are compared with existing literature, and these outcomes are subsequently generalized to shed light on broader impacts. This stage answers the pivotal "so what?" question, explaining the importance of the research and its implications and applications. The research culminates by answering the primary research question and its sub-questions, thereby explaining the contribution of the research to the standing body of knowledge.

Interviews

Selection criteria

The interviewees for the empirical research were carefully chosen based on specific selection criteria to capture diverse insights into modular construction integration in real estate development. The criteria revolved around their experience with modular construction, the scope of their professional expertise, and their focus on urban housing construction. These criteria ensured that the research was grounded in practical realities and comprehensively addressed the research questions. The selection criteria are summarized in the following Table 7:

Table 7: Respondents selection criteria

Criteria	Description
Modular Construction Experience	Interviewees must have hands-on experience with at least one modular construction project to ensure the practical relevance of their insights.
Scope of Experience	The range of expertise was intended to be varied to capture multiple perspectives. This included experts from different professional backgrounds and from various stages of the modular construction process.
Focus on Urban Housing Construction	Interviewees should have experience with housing construction within urban areas, given the unique challenges associated with urban construction such as space constraints, heightened regulations, and logistical complexities.

These criteria provided a solid foundation for the selection of interviewees, contributing to a comprehensive understanding of the integration of modular construction in the real estate sector.

The empirical research study comprised a series of interviews conducted with 11 participants. Table 1 provides an overview of the interviewees. The findings sections include quotes from different interviews identified by numbers, such as [1] referring to a quote from the Real estate developer/transaction manager at a private developer with 10 years of experience and worked on 1 failed modular project, as shown in Table 1.

Table 1: Summery of data collation

No.	Title	Working currently at organization	Years of expertise	Modular projects
1	Real estate developer/transaction manager	Private developer	10	1 project (failed)
2	Real estate developer + MT	Private developer	5	6
3	Real estate developer	Developing builder /Spin-off factory	10	0
4	Real estate developer/ architect	Corporate developer	3	3 (1 process)
5	Real estate developer	Developing builder	5	2 (1 failed)
6	Co-Founder/system developer	Digital system integrator	15	4
7	System architect	Vertical integration firm	6	8
8	Real estate developer	Vertical integration	10	4 (2 failed)
9	Real estate developer	Corporate developer	5	1
10 *	Real estate developer	Concept developers	8	1 (failed)
11 *	Real estate developer	Corporate developer	5	1

* Indicates that the interview was taken in the second round.

Semi-structured interviews

The decision to employ semi-structured interviews for this research was driven by the need for a nuanced understanding of the topic at hand. This format provided the flexibility to delve deeper into the experiences of the interviewees, while also allowing for the necessary structure to guide the conversation. Detailed interview invitations and the protocol utilized during these interviews are documented in Appendices A and B, respectively.

The semi-structured interviews revolved around the following key themes:

- Exploring the interviewees' journey towards the integration of modular construction.
- Understanding the specific tools, and strategies (mechanisms) employed in the integration process.
- Identifying the primary drivers and challenges encountered in their modular construction approach.
- Gathering views on strategies adopted by other companies in the sector.
- Capturing the outlook of modular construction from the interviewees' perspectives.

These thematic areas, while offering a structured guide, provided room for insightful discussions, contributing to the depth of the study. Steps were taken in this research to simplify the jargon in the semi-structured interview protocol.

1. **Pre-Interview Documentation**: Alongside the interview invitations, as documented in Appendix A, an introductory document was provided to participants. This document translated key concepts and terms pertinent to the research into layman's terms, which allowed interviewees to gain a foundational understanding of these terminologies prior to the interview.

2. **Paraphrasing and Providing Examples**: In the actual interviews, the researcher paraphrased complex or jargon-heavy ideas into simpler language. When a technical

term was inevitable, concrete, real-world examples or analogies were used to clarify the term's meaning.

3. **Immediate Clarifications**: During the interviews, if a participant seemed unsure or asked for clarification, immediate explanations were given in simpler terms. This was to ensure that the interview progressed based on a shared understanding.
4. **Open Questions**: The interview questions were designed to be open and exploratory, thus not necessitating an understanding of specific jargon to answer. This allowed the interviewees to express their perspectives and experiences in their own words.
5. **Avoidance of Jargon Where Possible**: Technical terms were avoided wherever possible. In the instances where these terms could not be omitted due to the nature of the topic, they were always explained in an easy-to-understand, accessible manner.

These methods facilitated the maintaining of jargon-free conversations during the interviews, which the researcher believes enhanced the quality and depth of the data collected. Your input on this matter is greatly appreciated, and the researcher is open to any further suggestions or advice you may provide.

Analysing data

Data collection approach

The data collection and analysis undertaken in this research adhered to a systematic approach. An exhaustive theoretical frame of reference was conducted to develop pertinent interview questions and acquire a thorough understanding of the background (Bryman, 2012). After conducting the interviews, the data were diligently recorded, transcribed, and coded. The coding process was facilitated by the ATLAS.ti software, a computer program designed for analysing qualitative research content. Data were partitioned into codes based on their theoretical significance, and these codes were labelled with categories and themes determined by the researcher. The coding process, guided by Saldana's (2021) code-to-theory model for qualitative inquiry, involved creating codes using a semi-open coding method.

Results Structuring

The structuring of the results aimed to categorize the data from the semi-structured interviews within one of six organizational strategies identified in the literature. A two-round interview process ensured a thorough examination of the data and an opportunity to identify any new structures not mentioned in the literature. The six identified strategies were:

1. Decentralized modular cluster.
2. Collaborative modular clusters
3. Virtual project-based companies
4. Spin-off factory
5. Core-periphery platform
6. Integrated hierarchical firms

The data was also examined in terms of the mechanisms employed within each strategy. This analysis was divided into two main categories: value proposition and operational system as shown in Figure 15. The value proposition examined critical areas such as target segment, product offering, and revenue model. In contrast, the operational system focused on the value chain, cost model, and organization. This systematic analysis allowed for a structured comparison of the various integration strategies, highlighting both their similarities and differences.

Lastly, the research identified and reported the main drivers and challenges for each approach. This step added depth to the understanding of why specific strategies and mechanisms were favoured over others and provided insights into the complex dynamics of integrating modular construction within the real estate development sector. All these elements combined create a comprehensive, clear, and replicable structure for understanding the research findings.

From Data to Codes to Themes to Theory

Initially, the data were encoded into concise phrases or words that captured the essence of the data. These codes were then grouped into categories such as "explains strategy," "mechanism," and "drivers/challenges," which amalgamated several codes to convey a more expansive meaning. The categories were subsequently attributed to specific strategies identified in the literature such as "Decentralized modular cluster," "Collaborative modular clusters," and so forth. In the final phase, these categories were designated with a distinct strategic approach that emerged from the interviews. These approaches where initially "Project-based," or "Product-based" this coding continued until data saturation was achieved—this point was identified when no new approaches emerged after a considerable number of interviews had been analysed. This caused the introduction of a third theme 'hybrid based" approaches. The labelling of these themes was intricately connected to the theoretical literature and included concepts like "mirroring," "mirror-breaking," "informal mechanism," "formal mechanism," "push/pull factors," and more. This progression from codes to themes and theories provided an in-depth and nuanced understanding of the research findings and provided a profound research discussion, shedding light on the intricate dynamics of integrating modular construction within the real estate development sector. This code to theory structure is illustrated in figure 18 below.

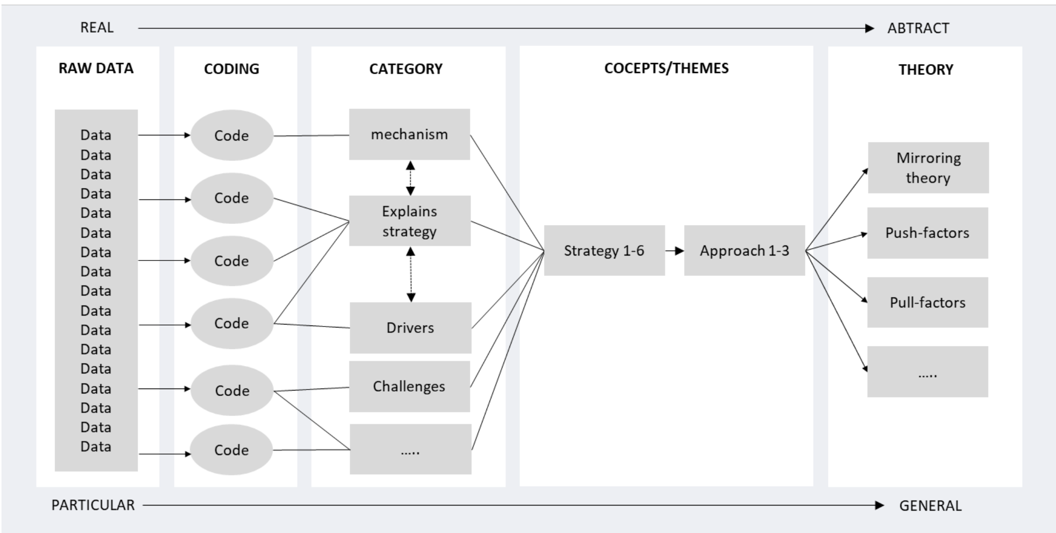


Figure 18: code-to-theory model adopted from Saldana (2021)

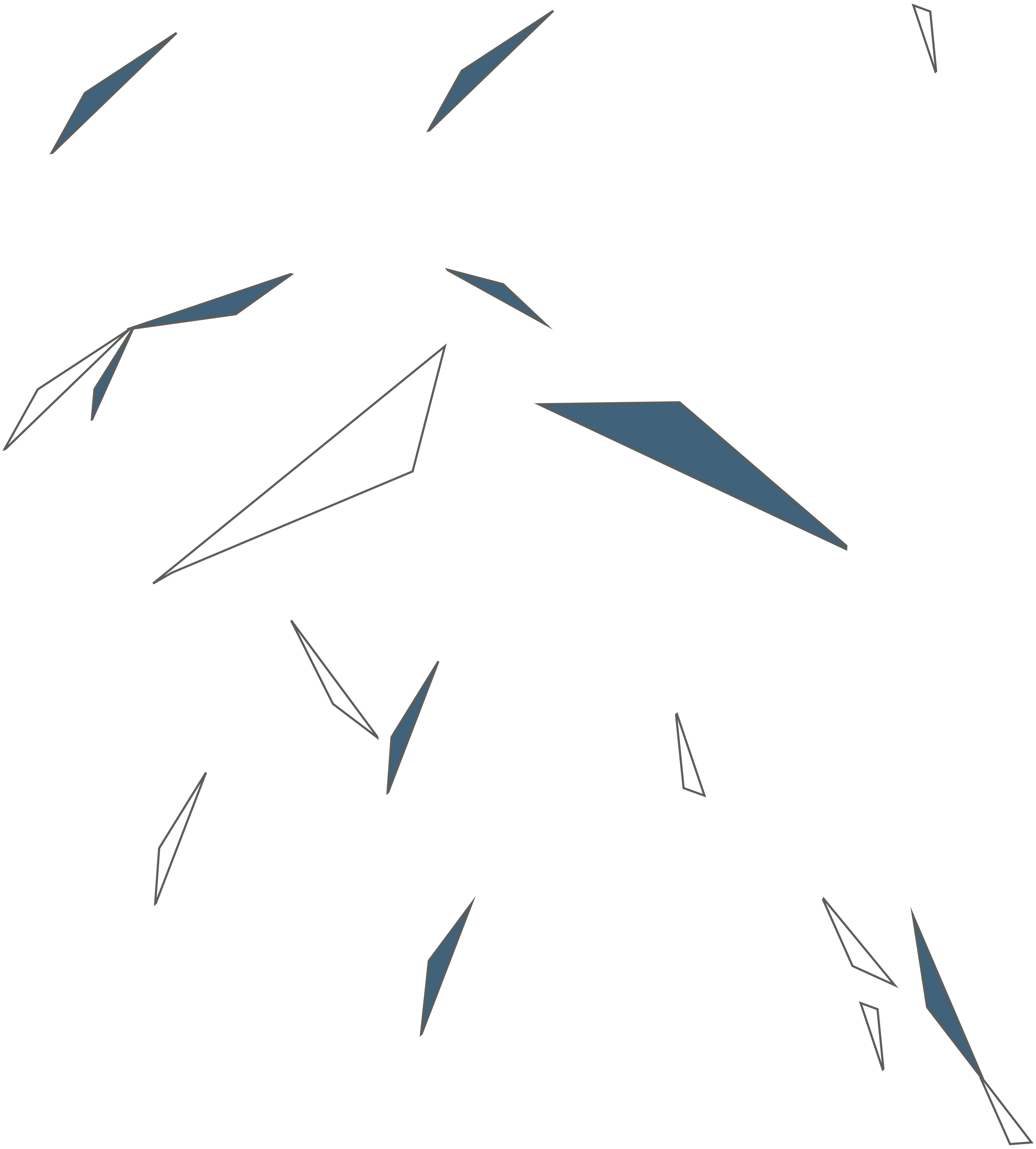
Data Plan and Ethical Consideration

This research adheres to a structured data plan and maintains rigorous ethical considerations, following the FAIR Data Principles which emphasize the findability, accessibility, interoperability, and reusability of data. As such, the complete research thesis can be found in the Delft University of Technology repository. The choice of writing the thesis in English ensures its interoperability, while a thorough explanation of each research step facilitates its reusability. All citations conform to the APA 6th referencing style, with a comprehensive list of references available at the end of the thesis.

The thesis aligns with the "Code of Ethics of the Delft University of Technology" and pays significant attention to ethical considerations in data collection, storage, use, and disposal, particularly with respect to data derived from human participants. It addresses legal aspects such as intellectual property, confidentiality, and integrity during data collection.

Interviews were conducted with informed personal and corporate consent, giving interviewees the option to withdraw or refrain from answering specific questions. Consent letters and interview protocols were provided to all participants, and their signed consent letters are available upon request. All data analysis materials were stored offline and will be deleted post-graduation. All personal information is maintained confidentially, and any data shared is properly anonymized.

Special ethical considerations were applied concerning the research group of real estate developers. This group was informed about the research purpose, methods, and potential applications. A debriefing was conducted following each interview, with a reassurance of confidentiality provided for any participant wishing to be anonymized. Respect for their privacy was upheld throughout the research, and their voluntary participation was without any harm. All these measures ensure that the research respects the dignity, rights, and welfare of the participants, reflecting the core values of ethical research practice.



4

Findings

Identifying three Key approaches for modular construction for real estate developers: A Qualitative Analysis from Eleven Expert Interviews

Introduction

The findings offer insights into integrating modular construction in the real estate development industry, drawn from interviews with real estate experts. Three approaches emerged: the project-based approach, favouring adaptability and customization; the Hybrid-based approach, combining elements of both project and product-based strategies; and the product-based approach, centred on standardized, repeatable solutions. The findings primarily derive from interviews with real estate developers, referenced as [1], [2], etc. (e.g. [3] refers to a quote from a Real estate developer for a mid-sized firm). A summary of the findings is provided in Table 8 on the next page.

#	Integration Approach	Integration	Integration Mechanism	Example Firm	Drivers	Chellanges	H	V	L
1	Project-based Strategy (Decentralized Modular Cluster)	Early involvement of key participants in traditional design-bid build	Manufacturing and assembly knowledge hub for collective design.	Traditional private developers	Market Responsiveness, Collaboration, Knowledge Sharing	Fragmentation, Truck Systems, Timing Issues			
2	Project-based Strategy (Collaborative Modular Cluster)	Preferred supplier network	long-term partnerships; selective broad offering	Progressive private developers	Increased Efficiency, Innovation, Supply Chain Integration	Partnership Management, Contract Negotiation, Standardization and Customization, Resource Investment	Informal	Informal	
3	Project-based Strategy (Virtual Project-Based Company)	Integrated project delivery	Collaboration among skilled professionals from different firms; Temporary coalitions	VORM2050	Cost Savings, Flexibility, Access to Talent, Unified Objectives, Collaboration	Technical Interdependencies, Resource Management, Trust-building, Intellectual Property, Complexity, Risk Management	Yes	Yes	Yes
4	Hybrid-based Strategy (Spinoff Factory)	Creating new products within an organization	Establishing a dedicated product development team; cross-functional collaboration	MorgenWonen (JOJO), mOptopper (VORM)	Innovation, Resource Utilization, Transitioning to Industrialized Construction	Supply Chain Management, Education, Unprofitability, Regulatory Complexities, High Initial Investment	Partly	Partly	Partly
5	Hybrid-based Strategy (Core-Periphery Platform Structure)	Collaboration with a core platform (Digital system integration)	Focus on specific product portfolio and industrialized construction	Suistainer.Home * Finch buildings*	Productivity, Cost-Effectiveness, Standardization, Collaboration and Coordination	Vertical Fragmentation, Configuration Engineering Solutions, Time Investment, Partner Selection	Informal	Partly	Yes
6	Product-based Strategy (Integrated Hierarchical Firms)	Vertical integration of multiple stages within the organisation or supply chain	Full integrated solution	Listerbuildings	Cost Reduction, Efficient Resource Allocation, Quality Control, Improved Coordination, Competitive Advantage	Investment and Capital Requirements, Complex Internal Supply Chain Management, Adaptability and Flexibility, Market Acceptance and Education	Yes	Yes	Yes

Table 8: overview of integration strategies from empirical findings. H= Horizontal integrated, V= Vertical integrated, L= Longitudinal integrated

* Firm act not as real estate developer but as core system to elaborate with real estate developer.

Approach 1: Project-based strategy

The first integration approach identified in this study is the project-based approach to integrate Modular Construction. This approach, according to the experts, prioritizes market profitability opportunities, often referred to as 'looking for project specific market demands [demand pull]' [1]. The primary focus of this strategy is to "gather specialized suppliers and subcontractors under the project developer's guidance" [5] to collectively develop and deliver a modular construction project, frequently convened explicitly for each project. Without a project, there is no reason for existence for cluster. The strategy emphasizes customization over uniformity. Expert [1], a strategic developer in the construction industry, draws a parallel to this approach with a concept termed 'mirroring.' He notes,

> *The temporary and flexible nature of these collaborations enables companies to adapt to the unique requirements of each project without significant investments in the structure or cognitive resources. It's an agile strategy that emphasizes customization over uniformity [1].*

To innovate, the project-based approaches can employ supply chain integration practices (SCIP's). The experts indicated the use of digital tools, among other things, to enhance efficiency, communication, and scalability. Expert [2] emphasizes that this approach focuses on digital tools and transparency with the aim to make processes smoother, faster, and more adaptable.

However, the project-based approach is not without challenges, predominantly dealing with fragmentation and complexity due to the project-specific and temporal nature of the teams and strategies. Although the dynamics that render these project-based strategies flexible also introduce ongoing and difficult-to-manage challenges. The task lies in managing these fluid elements to ensure smooth collaboration, effective knowledge transfer, and timely project delivery.

Within the project-based approach, three categories have been identified that use 'the project' as a starting point. This starting point determines how project developers attempt to restructure their organization to achieve modular construction. These three integration strategies - 1) Decentralized Modular Cluster, 2) Collaborative Modular Cluster, and 3) Virtual Project-Based Company - are discussed below. The different mechanisms employed, the key drivers, and challenges of the organizational structure will also be briefly touched upon.

Integration strategy 1: Decentralized Modular Cluster

Integration

The first integration strategy defined within the project-based approach is a "decentralized modular cluster," the most traditional organizational structure and often used by traditional private developers. It is not characterized by a form of horizontal or vertical integration. In this structure, multiple independent parties collaborate to deliver a product or service. These modules may be geographically dispersed and operate autonomously, but they work together and function collectively to achieve common goals. This model promotes innovation within the clusters, flexibility, and adaptability because "each module can quickly respond to market changes and customer needs without the need to adjust an entire organizational structure"[3]. This strategy is therefore often adopted by real estate development companies striving to create a flexible and adaptable organizational structure that can quickly respond to market shifts and customer inquiries.

Developers building within this framework utilize early involvement of key participants to integrate Modular Construction. Early involvement is implemented in different ways and at different stages with the overall goal of ensuring that "the design is truly based on that system or process"[6]. In general, early engagement projects arrange agreements with the modular component supplier during the conceptual or schematic (preliminary) design phase. These suppliers can be both a subcontractor and a main contractor. However, the extent of stakeholder engagement fluctuates across projects and may encompass multiple parties from the project's initial conceptual stages. In this context, the developer assumes a mediating role between the architect, the contractor(s), and the building system provided by the modular supplier.

Early involvement of essential participants promotes modular construction by providing collective knowledge in production and assembly during the design phase. By involving the modular supplier early, impractical ideas can be rejected early, allowing teams to focus on valuable concepts. Interviewees emphasized "the benefit of early involvement of the key subcontractors and supporting the design team to achieve a better result and prevent cost savings"[1]. Subcontractors "work closely with the architect"[4] and "dive deep into the details"[4] when discussing innovative ideas. Interviewed experts indicate that the benefits of this approach include early insight into exact construction costs and reducing the risk of later cost-cutting certain design elements, such as materials or unique features. Additionally, subcontractors can provide essential and direct feedback on feasibility aspects. One interviewee noted: "[sometimes] there are so many deviations from their standard product that they [the supplier] won't even start because they know what that means in practice"[2].

A project developer explained that early involvement is crucial because "the modular supplier will share information about what he has experienced, since there are not many reference projects".[4] This implies a cognitive scarcity about modular projects. The interviewees note that early involvement goes hand in hand with the need for financial transparency, as an agreement can only be reached under that condition. Several interviewees did not consider entering an early contract with the parties involved as a prerequisite. Often, a Letter of Intent (LOI) is strategically chosen because many changes can occur during the construction process, or the project may stall or not proceed at all. This approach also allows the developer to maintain more control over the project and take advantage of their specific and dominant position. Eventually, a (LOI) or contract is often only established with the module supplier, while a main contractor is identified at a later stage (after preliminary design) via the conventional Design-Bid-Build delivery method. This approach introduces the challenge of 'truck systems', which many contractors find unfavourable for various reasons, such as 'unfamiliarity with the supplier and increased risk exposure'[2]. This risk is then shifted to the developer, affecting the financial viability of the project. Another challenge of this strategy is that the project developer only orders the production of the modules when a permit is granted. "This results in a mismatch between the legal start date of construction and the technical feasibility of that moment"[5], negating the (financial) time-saving benefits of modular construction. This project-based method has also been criticized by various real estate professionals. As one expert noted in an interview:

"Ultimately, pulling the factory forward is just a very reactive approach [mirroring]. You react to old systems, which leads to the same problems as with the traditional way of building. You only do what is really necessary, without coming up with a constructive and well-thought-out solution."[5]

The reactive approach refers to operating from a traditional system 'mirroring'. Real estate developers only change their development structure when they genuinely can't do otherwise, as in this case with modular construction. A proactive way, according to the interviewee, would be to anticipate early by adjusting the development structure to overall trends in the market, not only when 'choosing that one building system.' [5] The "advantages of early supplier involvement lie not only in making modular construction feasible but improving the overall development process"[4]. This underlines the need for a more proactive and innovative approach to addressing the inherent challenges in the construction sector, rather than relying on outdated systems and reactive strategies.

Mechanisms

Figure 19 illustrates the mechanisms and strategies employed within the six pillars of the BMI. Subsequently, an elucidation of the key mechanisms used will be provided.

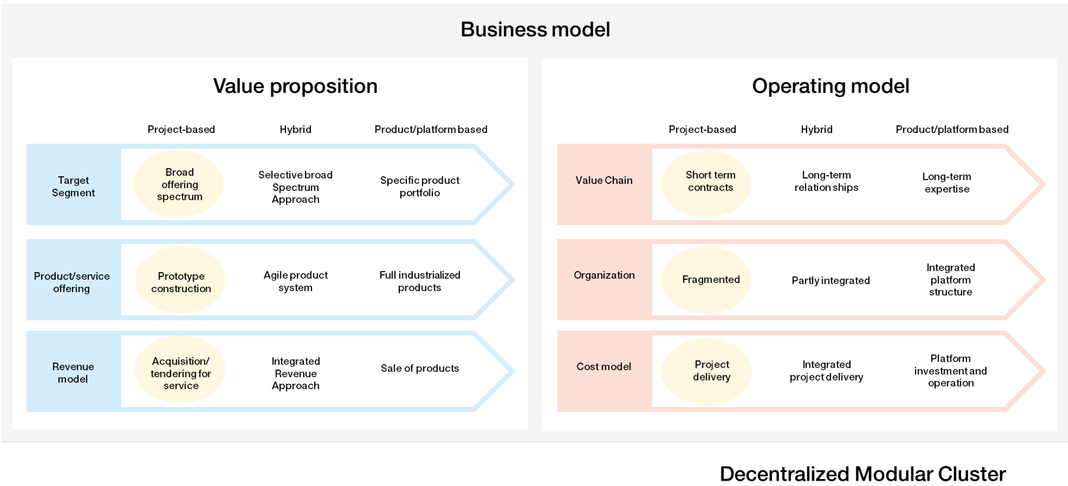


Figure 19: Business model and mechanisms of a Decentralized Modular Cluster

The use of specific mechanisms in the integration of a decentralized modular cluster model is crucial in real estate development. These mechanisms are distinctly implemented in the value proposition and the operating model.

Value Proposition Mechanisms

There are two significant mechanisms that constitute the value proposition in a decentralized modular cluster: target segment orientation and product/service offering. Regarding the target segment, Expert [1] explains, "When real estate developers integrate modular construction according to a project-based strategy, they focus on offering a wide spectrum of designs." This mechanism, exemplified by a project-based strategy, caters to a broad market and diverse customer groups within what is technically and economically feasible. Additionally, the utilization of prototype construction is a core mechanism in this context. Expert [2] states, "For each individual project, the design evolves through various stages, from conceptualization to engineering." As a example, a developer might "incorporate feedback from suppliers and subcontractors into the design at various stages, ensuring that the final product represents the best balance of price and value"[2].

Operating Model Mechanisms

The operating model covers mechanisms related to the revenue model, value chain, organizational structure, and cost model. The revenue model primarily emphasizes acquisition and tendering for services. As Expert [3] points out, "All suppliers and main contractors earn by charging a 'tail' over their costs but are excluded from the value enhancement of the location by the delivered products or services." This mechanism underscores the strategic importance of value creation at the location. When considering the value chain, short-term contracts characterize project-based approaches, which tend to have standalone projects and a highly fragmented structure." This mechanism facilitates a comprehensive understanding of all stakeholders and fosters the acquisition of essential knowledge resources and added value.

In terms of the organization structure, Expert [5] observed that "early involvement allows for *informal* vertical integration by reaching early agreements among all parties." This mechanism emphasizes the role of early agreement in fostering cooperation and integration within the typically fragmented structure of such projects.

Drivers and challenges

Drivers

1. *Market Responsiveness:* One primary driver of the project-based approach, as highlighted by many experts [1,2,3], is its responsiveness to market profitability opportunities, often referred to as 'demand pull'. This approach allows for agile adaptation to changing market conditions and customer needs.
2. *Collaboration and Knowledge Sharing*: Project-based teams, known for their temporary and flexible nature, often involve specialized suppliers and subcontractors. This dynamic fosters knowledge sharing and innovation across the industry [4,5]. Experts affirm that such collaborative environments can lead to cost reduction and improved product quality, effectively maximizing scarce cognitive resources.

Challenges

1. *Fragmentation and Complexity:* Despite its benefits, the decentralized modular cluster has its challenges. This strategy often grapples with fragmentation and complexity due to the temporal nature of teams and project-specific strategies. These factors can introduce a higher degree of complexity and potential for fragmentation.
2. *Truck Systems:* The risk of 'truck systems,' where contractors are forced to work with unfamiliar suppliers, can increase risk exposure [10]. This risk is often passed on to the developer, potentially affecting the financial viability of the project.
3. *Timing Issues:* A significant challenge in this approach is the timing of the commissioning of module production, which often only occurs when a permit is granted [2,3,511]. This can lead to a mismatch between the legal start date of construction and the technical feasibility at that moment, reducing the time-saving benefits of modular construction.

Integration strategy 2: Collaborative Modular Cluster

Integration

In the collaborative modular cluster model, various independent entities collaborate to create a product or service, resembling the concept of "modular production networks". These entities, or modules, specialize in different aspects of the process and work together to provide a comprehensive solution, fostering innovation, knowledge sharing, and resource pooling, leading to improved efficiency and effectiveness in delivering products or services. This strategy is used by developers that want to leverage the expertise and resources of multiple entities to create a comprehensive solution that meets the needs of their customers but looking more progressively to their organisation structure using SCIPs.

Real estate developers are addressing the balance between standardization and customization using collaborative clusters. Preferred suppliers or "makers" [3] are a key component of the collaborative modular cluster model. These suppliers are specialized in different aspects of the process and work together to provide a comprehensive solution that meets the needs of their customers. One interviewee emphasized the importance of standardization but acknowledged the necessity of customization, particularly in urban areas:

> *"Standardization is important in residential construction, but we see that customization is particularly needed in urban areas. We work with a network of Preferred Suppliers, whom we call 'makers.' We want to work with fixed parties and together design the best product, taking into account the price-quality ratio" [3]*

Per discipline, two or three parties are usually chosen by the developer for competition and risk-sharing purposes. Additionally, it is important to find architects who can create a design that fits within the standard building system, while still meeting the unique needs of each project.

> *"We work with concrete shells [standardization] and have a network of Preferred Suppliers with whom we collaborate. We can essentially create any desired home, but we do adhere to a standard construction system. We work with fixed suppliers and establish certain frameworks, such as the bay size of a home"I [2]*

This collaborative approach with preferred suppliers allows for flexibility in construction while ensuring adherence to a standard construction system that benefits both the builders and clients. However, the term "preferred suppliers" does not necessarily imply exclusive formal partnerships, as one interviewee notes:

> *"The ultimate goal is to have a learning organization and project team where everyone collaborates and learns from previous projects. However, this is not always possible, and we try to work with the same parties as much as possible."[3]*

The developers indicate that there is a cluster of trusted partners over the course of various projects, with a few occasional new players. These new players are often strategically chosen for their specific (regional) knowledge, logistics, or relational reasons for the project. For example, "because the architect is well-liked by the design committee of a certain municipality, or because the demolisher has a landfill site closer by" [6].

However, the developers also note that there are disadvantages to this approach, particularly in managing all of the partnerships which requires significant cognitive and financial resources. One challenge of a collaborative modular cluster approach is managing partnerships with multiple suppliers. This requires significant resources, both in terms of time and money. As one interviewee notes:

> *"Managing all of the partnerships requires a lot of time and effort. It's not just about finding the right partners, but also about maintaining relationships and ensuring that everyone is on the same page" [3].'*

One example of the challenges that can arise when working with preferred suppliers is illustrated by the experience of a developer who aimed to commence a project with a specific modular supplier. This decision, however, resulted in a deterioration of the relationship with their standard main contractors. As one interviewee noted, "ultimately, most modular builders are linked to a fixed main contractor with whom they have experience." [2] The developer's decision to partner with a particular modular supplier, motivated by sustainability and aesthetic considerations, posed a challenge in the negotiation of a contract with a primary contractor. Eventually, the developer had to resort to their standard suppliers, highlighting the difficulties of working with new and untested suppliers within this model.

It is worth noting that such challenges are also observed in the decentralized model of early key partner involvement, which highlights the significance of involving essential participants, such as modular suppliers, early on in the project to foster modular construction. However, as demonstrated in the example, collaborating with new and untested suppliers can create difficulties in contracting with a main contractor, emphasizing the need for careful consideration of supplier relationships and their potential impact on the overall project, even in models that prioritize early engagement and collaboration.

Mechanism

Figure 20 illustrates the mechanisms and strategies employed within the six pillars of the BMI. Subsequently, an elucidation of the key mechanisms used will be provided.

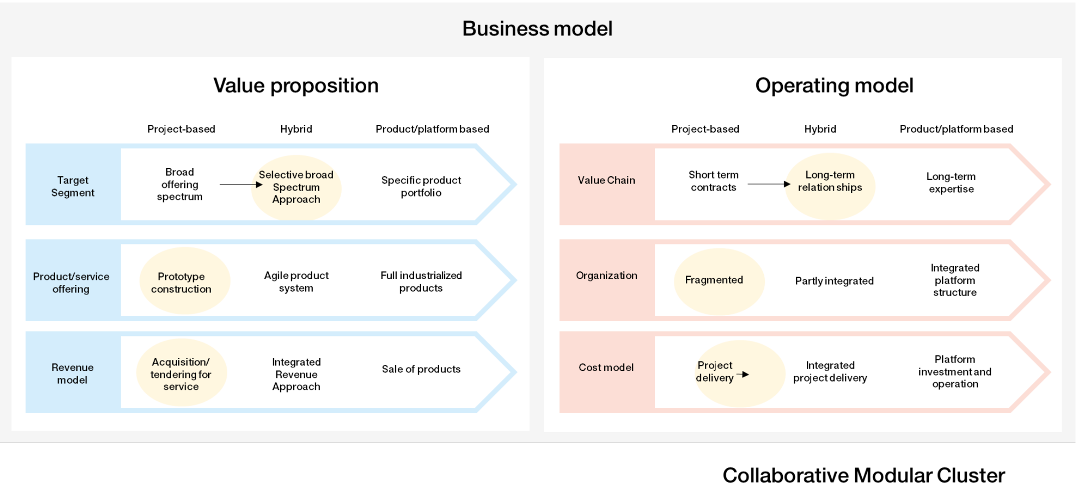


Figure 20: Business model and mechanisms of a Collaborative Modular Cluster

Value proposition

A key mechanism shaping the value proposition of a collaborative modular cluster model is a shift from a broad offering spectrum to a selective broad spectrum. This shift is facilitated through the integration of standardization and customization, using the expertise of Preferred Suppliers or "makers" [3]. In this model, real estate developers selectively offer a broad spectrum of designs. The selection is driven by a balance of standardization and customization to cater to a broad market and diverse customer groups. Developers work with a network of preferred suppliers who specialize in different aspects of the construction process, enabling them to provide a comprehensive solution that can be customized to the unique needs of each project. This balance of standardization and customization enhances the developers' ability to offer a selective broad spectrum of solutions, tailored to meet specific market demands.

Operating model

In the operating model of a collaborative modular cluster, a significant shift occurs from short-term contracts to long-term relationships. This shift is fundamentally driven by a change in the nature of the partnerships established within the model. As one developer describes, "The ultimate goal is to have a learning organization and project team where everyone collaborates and learns from previous projects. However, this is not always possible, and we try to work with the same parties as much as possible" [3].

In this model, developers foster long-term relationships with a select network of preferred suppliers, often working with the same parties across multiple projects. This practice promotes learning and collaboration, with developers and suppliers evolving their partnership over time, sharing knowledge, and mitigating risks collectively. This significant shift from short-lived relationships, common in project-based approaches, to long-term, collaborative partnerships in the collaborative modular cluster model, fundamentally changes the operating model, enabling developers to optimize the overall construction process.

Drivers and challenges

Drivers

1. *Increased Efficiency and Effectiveness:* The use of preferred suppliers or "makers" who specialize in various aspects of the construction process allows for increased efficiency and effectiveness in delivering products or services. Collaborative modular cluster model fosters innovation, knowledge sharing, and resource pooling. It ensures a balance between standardization, important for maintaining consistency, and customization, essential for catering to specific client needs.
2. *Fostering Innovation:* Independent entities in a collaborative modular cluster model foster innovation by bringing unique perspectives and specialization to the table. These entities collectively contribute to the creation of a comprehensive solution, enhancing the overall offering.
3. *Supply Chain Integration Practices (SCIPs):* Through the adoption of supply chain integration practices, project organizations can transition from a decentralized modular cluster to a 'collaborative modular cluster.' This form of informal integration facilitates collaborative efforts among participants from different firms, promoting enhanced coordination, communication, and trust.

Challenges

1. *Management of Partnerships:* The collaborative modular cluster approach requires managing multiple partnerships, which requires significant cognitive and financial

resources. Ensuring that everyone is on the same page, maintaining relationships, and finding the right partners can be time-consuming and challenging.

2. *Negotiating Contracts:* Working with new and untested suppliers can create difficulties in contracting with a main contractor. This challenge is illustrated by the experience of a developer who aimed to commence a project with a specific modular supplier. The decision resulted in a deterioration of the relationship with their standard main contractors.
3. *Resource Investment in SCIPs*: While SCIPs are seen as beneficial for the integration approach, they can be resource intensive. Firms often complain about the resources dedicated to these practices, even as they acknowledge the benefits of exploring new interdependencies.
4. *Balancing Standardization and Customization:* Finding the right balance between standardization and customization is a constant challenge. While standardization is essential for efficiency and consistency, customization is often needed to cater to specific client needs and contexts, particularly in urban areas.

Integration strategy 3: Virtual Project-Based Company

Integration

Interview insights revealed the emerging concept of a virtual project-based company. Such a company gathers skilled professionals from various geographical locations to address a specific project or task. As Expert [1] noted, "This method allows for cost savings, provides flexibility, and access to a broader talent pool. We can harness the best of the best, regardless of their location."

Expert [2] expanded upon this idea, introducing the notion of Integrated Project Delivery (IPD). According to them, "IPD takes this approach to the next level by forming a virtual company. Here, actors from different firms collaborate as one entity with unified objectives and goals." This innovative method, as Expert [2] described, leverages digital communication tools for swift team assembly, eliminating the need for investing in permanent infrastructure or personnel.

However, expert [3] shed light on some of the challenges tied to integrating virtual project-based companies. They warned of potential difficulties in co-developing technical interdependencies in mutual relationships, stating, "The interlinked nature of these relationships can be complex, possibly straining resources and impeding progress." [3]

Further, Expert [4] highlighted the possible cognitive and financial resource waste associated with this approach. "While the model offers flexibility and cost savings, there's also a risk of resource waste if not managed properly. Attention to detail and rigorous management are necessary to prevent this," they explained [4]. This caution suggests the need for careful planning and management to maximize the benefits of this model.

The experts describe this strategy as “prioritizing collaboration over competition using digital systems”[8]. There are some examples of the virtual project-based company model being used, but it is not yet widely adopted. One practitioner noted that this approach challenges the traditional mindset of the "same old low bid mentality," [7] where parties would compete to offer the lowest price and subsequently fight over rights to every cent earned. Instead, the virtual project-based company model emphasizes working with a fixed number of parties, promoting a more cooperative environment. A practitioner describes this way of working as follows:

> *" I mean, it's actually a way we're letting go of the old-fashioned and expensive building concept and designing based on data and algorithms, you know? We take the manual elements out of the development process and automate them using parameters we enter into a special software program [that enables communication among all teams]."[6]*

VORM2050 is as a successful example of this strategy, illustrating the potential advantages of leveraging the expertise and resources of multiple firms for complex projects (VORM, 2023). The dynamic collective of VORM2050 is activated upon starting a project [7], allowing the organization to harness the diverse expertise and resources at its disposal. As a practitioner explained, "No company has all the expertise it needs in-house. That's why we work with a network of trusted partners who can provide the expertise we need, when we need it."[7] The "Circular Housing Project" showcases VORM2050's application of this model, as the company collaborated with several firms specializing in circular building design to develop sustainable, circular homes.

While the virtual project-based company model shows promise, practitioners have also noted several challenges that must be addressed to ensure success. For instance, one challenge is building trust among participating parties, which involves fostering clear communication, transparency, and accountability. Another challenge lies in establishing clear guidelines and agreements regarding intellectual property ownership and sharing, which is crucial to prevent disputes and maintain harmonious working relationships.

Practitioners have also pointed out the complexities of managing virtual project-based companies, which require seamless integration of workflows, systems, and processes. This may necessitate investment in new technologies and collaboration tools. Finally, while the virtual project-based company model aims to reduce risks, practitioners have noted that it can also introduce new risks. Developing robust risk management strategies and contingency plans is essential to mitigate these risks.

In light of these insights, the virtual project-based company model emerges as an innovative approach to project development that emphasizes collaboration over competition. To fully capitalize on the benefits of this approach and ensure project success the coordinating role of the real estate developer is utmost important.

Mechanism

Value Proposition

Expert [1] highlighted a significant shift in all mechanisms assessed in this study. According to them, "There's been a change towards a more selective spectrum of target segments and the use of an agile product system." This agile system denotes a process of frequent iterations, continuous adaption based on feedback and insights, and work conducted in short sprints. Expert [2] expanded on the business aspects, stating, "Various firms formally unite for the project, sharing financial risks and rewards, indicating an integrated revenue approach." This model, therefore, exhibits a joint risk and reward structure, reflecting a unified approach towards financial management in these virtual setups.

Operating Model

The operating model also presents a drastic shift from the traditional approach. Expert [3] elucidated this, explaining, "It's remarkable to see how people are utilized based on their skills rather than what the company has to offer." [3]. This fluid role distribution results in formal vertical integration among project developers, architects, builders, and suppliers. But, as Expert [4] notes, it also leads to horizontal integration between various subcontractors, stating, "This arrangement facilitates both vertical and horizontal integration, overcoming the typical fragmentation of roles and responsibilities."[4] As per Expert [5], initial steps have also been taken to mitigate longitudinal fragmentation by always selecting from a fixed pool of companies, using the same systems and tools. They elaborated, "By choosing partners from a stable pool and using shared tools, knowledge is transferred from one project to another, enabling continuous learning and process improvement." This practice allows the virtual company to capture and leverage institutional knowledge across projects, enhancing their ability to deliver consistent, high-quality results.

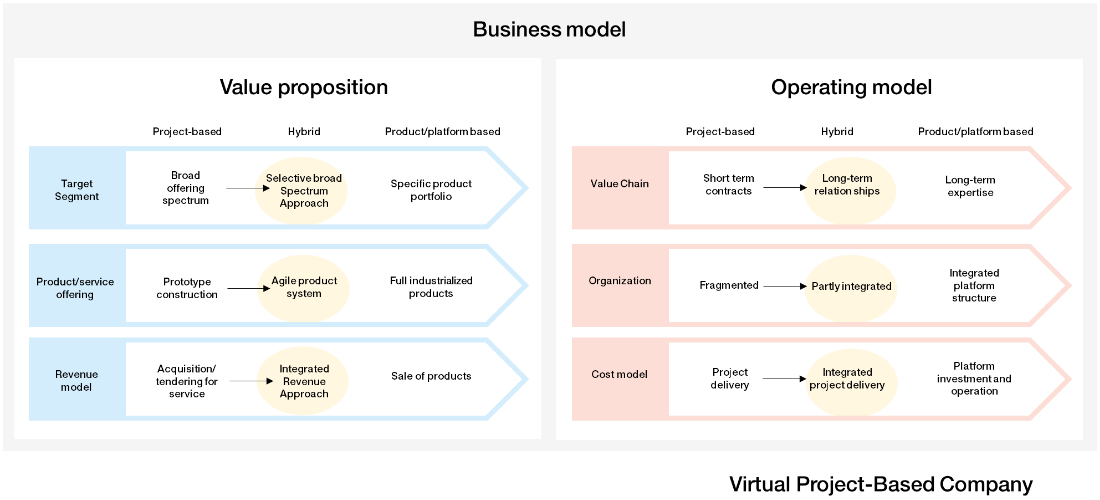


Figure 21:Business model and mechanisms of a Virtual Project-based Company

Drivers and challenges

Drivers:

- *Cost savings*: As highlighted by Expert [1], the virtual project-based company model results in cost reductions by eliminating the need for permanent infrastructure or personnel.
- *Flexibility*: The same expert also pointed out that this model provides flexibility, as it allows for swift team assembly using digital communication tools.
- *Access to a broader talent pool*: The model enables companies to tap into a global pool of skilled professionals, as mentioned by Expert [1].
- *Unified objectives and goals*: Integrated Project Delivery (IPD), a subset of this model, emphasizes the unification of goals and objectives across different firms, leading to more effective collaboration, as explained by Expert [2].
- *Emphasizing collaboration over competition*: This model fosters a cooperative environment by encouraging parties to work together, instead of competing, as described by Expert [8].

Challenges:

- *Co-developing technical interdependencies*: Expert [3] identified the complexity of interlinked relationships in this model as a potential hurdle.
- *Potential resource waste*: The possibility of cognitive and financial resource wastage was pointed out by Expert [4], who emphasized the need for careful management to avoid this risk.
- *Trust-building among parties*: As highlighted by practitioners, building trust, clear communication, transparency, and accountability among the participating parties are crucial.
- *Intellectual property issues*: Establishing clear guidelines and agreements regarding intellectual property ownership and sharing is necessary to prevent disputes and maintain harmonious working relationships, as noted by practitioners.
- *Complexity of managing virtual companies*: The seamless integration of workflows, systems, and processes is required, which might necessitate new technologies and collaboration tools.
- *Risk management*: While the virtual project-based company model aims to reduce risks, it can also introduce new risks, as pointed out by practitioners. This underlines the importance of having robust risk management strategies and contingency plans.

Approach 2: Hybrid-based strategy

Hybrid-based approaches in the context of integration strategies refer to the combination of project-based and production-based methodologies. These approaches recognize the value of incorporating elements from both traditional project-based construction and more industrialized product-based methods (approach 3).

In the Spinoff Factory integration strategy, the Hybrid-based approach allows project-based companies to leverage the advantages of industrialized construction while still maintaining flexibility of a project-based approach. By establishing a dedicated factory or business unit derived from the parent company, the organization can transition from a project-based model to a more product-focused approach. This shift fosters a learning culture between project requirements and the need for sustainable continuity in a factory environment. It enables the development of new products and promotes innovation and entrepreneurship within the organization.

Similarly, in the Core-Periphery Platform Structure integration strategy, the Hybrid-based approach combines the core platform's centralized coordination and specialized functions with the contributions of peripheral players or service providers. The core platform handles essential functions such as system development, communication, and data management, while the peripheral players provide specialized products or services to customers while remaining project based, due to the open system of the core. This collaboration between the core and the periphery promotes scalability, flexibility, and access to a wide variety of services.

The Hybrid-based approaches offer a balance between the project-based approach's adaptability and the production-based approach's efficiency. By incorporating elements from both approaches, organizations can capitalize on the ”benefits of standardized processes, quality control, and cost-effectiveness, while still accommodating project-specific requirements” [9] fostering viability and flexibility. It allows for a more streamlined and focused approach to construction while retaining the ability to tailor products and services to meet specific project needs.

Overall, the concept of Hybrid-based approaches acknowledges the importance of striking a balance between project-based and production-based methods. It recognizes that different projects and contexts may require varying degrees of flexibility, customization, and standardization. By integrating elements from both approaches, organizations can optimize their construction processes, enhance productivity, and deliver high-quality outcomes while adapting to the unique demands of each project [4.6.9].

Integration strategy 4: Spinoff Factory

Integration

A spinoff factory is an organization that focuses on creating a new product that can be offered to the market. This model encourages innovation and entrepreneurship within the organization, as employees are given the opportunity to develop and bring new ideas to market.

> *The parent company can provide resources, support, and guidance to the spinoffs, which can lead to mutual benefits and synergies. [8]*

The spinoff factory business model entails the creation of a factory or business unit that originates from an established project-based company. This strategic approach enables project-based companies to shift towards a more industrialized construction approach. It fosters a learning culture between project requirements and the need for sustainable continuity in a factory environment. Cost savings are often expected since production and assembly can be carried out in a controlled environment, thereby capturing the value of modular construction. As one interviewee stated: "Ultimately, we started this for cost savings and efficiency gains because you can produce and assemble everything in a controlled environment."

Experts indicate that mainly large developers focus on producing concept homes that come directly from the factory, ”since they have the [financial] resources [1]. However, they face challenges in managing supply and demand. One interviewee noted that "large firms in modular housing construction struggle with controlling supply and demand. They lobby with companies and promote the development of new residential areas to maintain their production process." [2] Furthermore, a challenge with this model is consistently communicating and providing training to the existing supply chain about the opportunities and potential of the new factory.

In addition, developers who collaborate with partners (internal or external) to develop a specific concept often do so because they want to create a product that aligns well with their own business philosophy and have sufficient resources to set up such a project. One interviewee described their spin-off product as follows:

> *[We developed a] circular single-family home, where we have carefully considered technical solutions that are truly circular and not just buzzwords. It is a well-conceived concept that, unfortunately, has not yet been realized. However, the design has already been fully engineered by our contractor and is available in BIM, so construction could begin tomorrow if commissioned. We are fortunate to have 15 to 20 contractors in-house, who have also been involved in the engineering of this innovative concept [6].*

The concept had an *unprofitable peak*, which means that costs were higher than the revenues. Causing that the concept was too expensive for the market and the location where the developer wanted to place it. However, it is interesting to understand why this concept is more expensive than traditional homes. Respondents indicate that this is primarily because the starting points of such concepts are often based on sustainability, resulting in the use of more expensive bio-based materials and the lack of scaling. Another reason is described as follows:

> *The reason why the concept has not yet been realized is due to several factors. For example, suitable locations for building the concept have not been found yet, and it remains difficult to obtain financing for innovative [sustainable] projects. Moreover, we are dealing with complex laws and regulations, and often there is a need for extensive consultation with municipalities and other involved parties. But we remain committed to realizing this and other sustainable concepts in the future.[7]*

In the design and development of these products, various parties are involved, including the engineering firm, the developer, the contractor, and suppliers. One developer mentioned that: "In this concept, the aim is to keep as much procurement and expertise within the group as possible, so that the money circulates internally rather than being spent externally." [8]

In the context of the spinoff factory business model, the developer's role evolves to focus more on strategically positioning their product within the market. This shift requires the developer to make informed decisions and carefully consider trade-offs concerning the feasibility and practicality of various aspects of their product offering. As one interviewee noted:

> *"That is also a bit of a game between the developer and the contractor in that case. And the choice, right? Because industrialized construction also means that you don't want to do everything at once and that you make choices about what you do and do not offer, which differs significantly from traditional construction." [9]*

This statement underscores the importance of collaboration between developers and contractors, as well as the need for flexibility and adaptability in product offerings. Industrialized construction, as opposed to traditional methods, demands a more streamlined and focused approach to building design and execution, which may necessitate making difficult choices regarding the inclusion or exclusion of specific features or construction techniques.

Mechanism

Value Proposition:

In the context of a spinoff factory, Expert [1] sheds light on the organization's value proposition. As per them, the entity focuses on a specific product portfolio, closely aligned with the current needs of target segments. They explained, "This commitment to serving specific needs results in fully industrialized products, tailored to match the expectations and requirements of the market."

However, while there's a specialized product focus, the revenue model, as stated by Expert [2], still largely follows a project-based approach, albeit with a greater degree of integration. The expert elaborated, "The factory often operates as a distinct entity, yet shares in the value creation at the location. This integrated model promotes shared benefits and harmonized operations."[2]

Operating Model:

When it comes to the operating model, Expert [3] indicates that long-term expertise is embedded in the value chain. They noted, "This structure allows the organization to capitalize on the specialized knowledge and skills developed over time, yielding superior products and services"[3]. The organization exhibits partial integration, as clarified by Expert [4]. Although it collaborates with a factory, each project often involves local companies for specific complex tasks. The expert mentioned, "Project developers adopting this approach need to invest in a factory and in the development of a concept. This requires substantial upfront investment."

Finally, when it comes to the cost model aspect, it is important to consider the insights provided by Expert [5]. While the spinoff factory requires a substantial initial investment, it is not typically the only source of income for project developers. Land acquisition continues to be the main revenue generator, leading to a partially integrated cost model. Expanding on this point, the expert explains that despite the initial capital needed for establishing the factory and developing the concept, the spinoff factory usually does not serve as the sole revenue source. This arrangement enables a partially integrated cost model to be maintained [5].

Figure 22 shows the Hybrid-based approach of mechanisms within the business model.

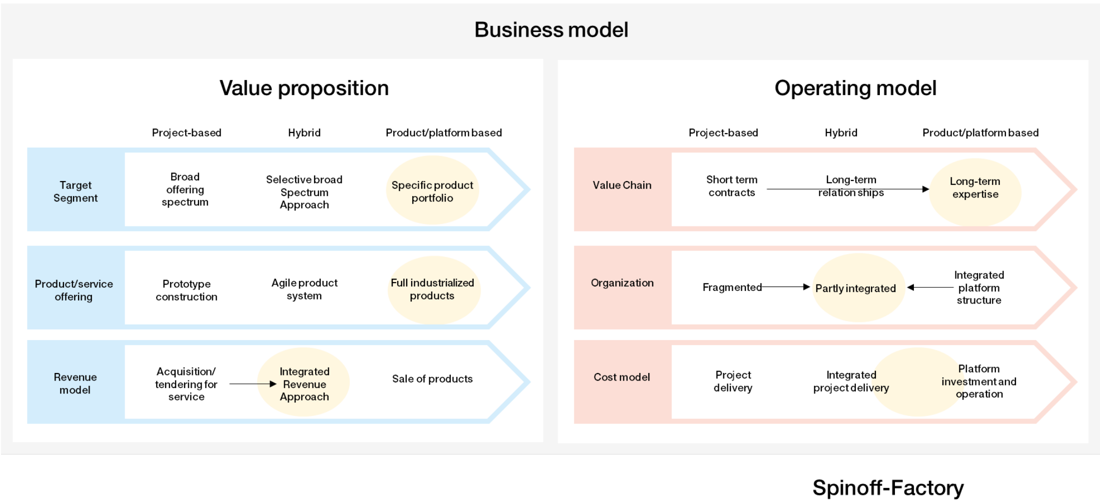


Figure 22: Business model and mechanisms of a Spin off-factory

Drivers and challenges

Drivers

- *Focus on Innovation*: A spinoff factory encourages the development of new products for the market, fostering innovation and entrepreneurship within the organization. It allows employees to materialize their ideas into market-ready products [1].
- *Resource and Support:* The parent company can provide resources, support, and guidance to the spinoffs, leading to mutual benefits and synergies [2].
- *Transition to Industrialized Construction:* This strategy permits project-based companies to move towards a more industrialized construction approach. It enables a learning relationship between project demands and the continuity required in a factory setting [3].

- *Cost Savings and Efficiency:* Production and assembly can occur in a controlled environment, which often results in cost savings and efficiency gains. It also allows the capture of the value of modular construction [4].
- *Alignment with Business Philosophy:* Developers often collaborate with partners to develop a product that aligns well with their business philosophy and have adequate resources to undertake such projects [5].
- *Strategic Product Positioning:* The developer's role shifts towards focusing more on strategically positioning their product within the market [6].

Challenges

- *Managing Supply and Demand:* Large developers focusing on producing concept homes straight from the factory face challenges in managing supply and demand [7].
- *Education of the Supply Chain:* There's a constant need to educate the existing supply chain about the possibilities of the new factory, which can be time-consuming and challenging [8].
- *Unprofitability:* Some innovative concepts may initially prove unprofitable, where costs exceed revenues. These products might be too expensive for the market or the location where they're intended to be placed [9].
- *Regulatory Complexities and Financing*: There are challenges related to finding suitable locations for building the concept, securing financing for innovative projects, dealing with complex laws and regulations, and engaging in extensive consultation with municipalities and other involved parties [10].
- *Trade-offs and Adaptability: I*ndustrialized construction demands a more streamlined and focused approach, which may necessitate making difficult choices about what to include or exclude in product offerings [11].
- *High Initial Investment:* Setting up a spinoff factory requires substantial upfront investment. Despite the potential for high returns, the initial capital outlay can be a significant barrier.

Integration strategy 5: Core-Periphery Platform Structure

Integration

The integration strategy of the Core-Periphery Platform Structure within the context of modular construction involves real estate developers engaging in a formal or informal partnership with a core platform [1]. This partnership sets the design principles and construction methods, while the actual production is often carried out by established suppliers or peripheral players [1]. The following quotes from the expert interviews provide insights into this integration strategy and its implications:

> *"Developers working with such a platform approach it as early partnership involvement, where they collaborate with a flexible construction system." [1]*

This quote emphasizes that real estate developers view their involvement with the core platform as an early partnership. They actively collaborate with a flexible construction system, establishing a close working relationship from the early stages of the project. This partnership enables them to shape the design principles and construction methods according to their specific project requirements.

> *"The standardization is primarily embedded in the parametric model. While you can make anything in principle, it's the model that provides standardization or predefined agreements." [2]*

This quote highlights the role of standardization within the core platform. The parametric model serves as the basis for standardization, ensuring consistency and predefined agreements. While the design principles and construction methods can be flexible and adaptable, the parametric model provides a standardized framework that guides the production process within the core.

> *"In the Core-Periphery Platform Structure, a central platform connects various peripheral players or service providers, facilitating interactions and transactions." [3]*

This quote emphasizes the central platform's role in connecting peripheral players or service providers. It serves as a hub for communication, coordination, and transactional activities within the construction ecosystem. The central platform often handles essential functions such as payment processing, communication, and data management, promoting scalability, flexibility, and access to a wide variety of services for customers. Two distinct models of core construction emerge from the interviews conducted:

1. The first model is a fully flexible, parametric system where peripheral participants and contractors can actively engage and contribute, as can be seen in the operations of Sustainer.homes.

Example 1: Imagine a real estate developer forming a partnership with a modular construction platform operating at the core level. During the design phase, both entities collaborate intensively, defining the principles and parameters that will guide the project. Following this mutual agreement, the core platform creates a parametric model to steer the production process. The developer subsequently recruits specific suppliers or peripheral participants to produce the modular components, conforming to the standardised model. This strategy guarantees alignment of the modules with the original design principles, enhancing overall integration.

2. The second model involves companies such as Finch buildings, which have predefined designs for their modules but are open to modifications through collaboration with peripheral players.

Example 2: Consider a real estate developer working with a core platform with a robust, predefined parametric model for low-rise construction. The developer and the core platform collaborate to modify the existing model to fit the developer's unique project, addressing factors like floor plans, facade design, and structural requirements. Following the revision, the core platform generates the standardized modules in accordance with the adjusted parametric model. To manage on-site assembly and finishing works, the developer collaborates with specialized suppliers or peripheral participants, thereby ensuring the modules' seamless integration into the final building structure.

These examples illustrate how real estate developers integrate with the Core-Periphery Platform Structure in modular construction. The partnership with the core platform allows them to establish the design principles and construction methods, while peripheral players handle the actual production of standardized modules based on the agreed-upon parameters. This integration strategy ensures a collaborative and efficient approach to modular construction, combining design flexibility with standardized production processes.

Mechanism

The integration of the Core-Periphery Platform Structure in modular construction involves various mechanisms that shape the collaboration and operational aspects of the construction ecosystem. These mechanisms were identified through expert interviews with real estate developers [1]. The following quotes provide insights into these mechanisms:

> *"By deciding to collaborate with a core system, the developer limits the product portfolio to specific offerings, depending on the flexibility of the system itself. The product is fully industrialized." [1]*

The value proposition of the Core-Periphery Platform Structure lies in the focus on a specific product portfolio. The decision to work with a core system allows developers to leverage the industrialized nature of the construction process. The flexibility of the core system determines the breadth of offerings that can be provided. The product itself is fully industrialized, enabling enhanced productivity, cost-effectiveness, and quality control. The revenue model is closely tied to the collaboration or integration with the core system and its associated suppliers, creating a symbiotic relationship where the success of the developer relies on effective partnership and coordination.

> *"The operating model is determined by the chosen core system, which defines the value chain and establishes long-term expertise. All partners within the ecosystem are required to work with this core system, leading to both horizontal and longitudinal integration. However, vertical fragmentation still exists as different parties need to be engaged throughout the project lifecycle." [1]*

The operating model within the Core-Periphery Platform Structure is heavily influenced by the chosen core system. The core system defines the value chain and sets the framework for the entire construction process. It establishes long-term expertise within the ecosystem. All partners involved in the construction process are required to work with this core system, promoting horizontal, and longitudinal integration. This integration ensures seamless collaboration and coordination among various stakeholders. However, vertical fragmentation may still exist as different parties, such as suppliers or specialized contractors, need to be engaged at different stages of the project.

The mechanisms employed to integrate the Core-Periphery Platform Structure in modular construction provide several benefits. The focus on a specific product portfolio allows for industrialization and enhanced efficiency. The operating model, guided by the chosen core system, fosters collaboration, expertise development, and integration among partners.

These findings highlight the value proposition and operational aspects of the Core-Periphery Platform Structure in modular construction. By collaborating with a core system and adhering to its operating model, developers can capitalize on the benefits of industrialization, ensure effective collaboration with partners, and achieve improved project outcomes. The integration mechanisms employed create a framework that optimizes construction processes, leading to enhanced productivity and cost savings.

Figure 23 shows the Hybrid-based approach of mechanisms within the business model.

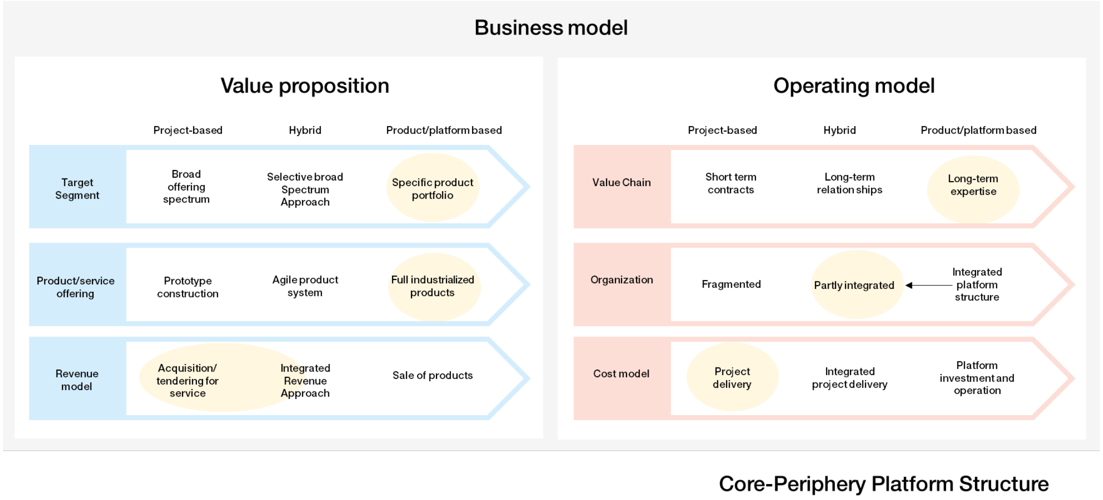


Figure 23: Business model and mechanisms of a Core-periphery platform structure

Drivers and challenges

Main drivers of the Core-Periphery Platform Structure integration in modular construction:

- Value proposition: Developers recognize the benefits of collaborating with a core system, which allows for a specific product portfolio [1]. The focus on a limited range of offerings streamlines the industrialized construction process, leading to enhanced productivity, cost-effectiveness, and quality control. The revenue model relies on effective collaboration and integration with the core system and its suppliers.
- Design principles and construction methods: Real estate developers actively engage in early partnership involvement with the core platform, shaping the design principles and construction methods according to their project requirements [1]. This collaboration ensures that the modules align with the desired design and construction standards.
- Standardization: The core platform utilizes a parametric model to provide standardization and predefined agreements [2]. While design principles and construction methods can be flexible, the parametric model establishes a standardized framework that guides the production process within the core. This standardization promotes consistency, efficiency, and coordination among various stakeholders.
- Collaboration and coordination: The central platform acts as a hub, connecting peripheral players and facilitating interactions and transactions [3]. This promotes horizontal and longitudinal integration within the construction ecosystem, enabling seamless collaboration and coordination among different partners involved in the process.

Challenges in implementing the Core-Periphery Platform Structure integration:

- *Vertical fragmentation:* Despite the integration facilitated by the core platform, vertical fragmentation persists as different parties need to be engaged throughout the project lifecycle [1]. Engaging multiple suppliers or specialized contractors at different stages of the project can pose challenges in terms of coordination and communication.

- *Configuration engineering solutions:*

  In the core-periphery platform structure, engineering solutions need to be configured, which means projects have limited options within the product platform. This limitation can restrict design flexibility and innovation, leading to longer innovation timelines when working with long-term partners in the periphery.

- *Time investment:* Developing and adapting the parametric model and collaborating with the core system require a significant investment of time and resources [2]. Customizing the model for specific projects and ensuring compatibility with the chosen suppliers and partners can be time-consuming.

- *Partner selection:* The core platform often chooses not to establish fixed partnerships with producers and suppliers to maintain price competitiveness and allow project developers to select their own compatible construction partners [2]. However, this requires careful selection and evaluation of partners who can work effectively with the core system.

Overall, while the Core-Periphery Platform Structure offers numerous benefits, such as enhanced industrialization and collaboration, it also presents challenges related to vertical fragmentation, configuration constraints, time investment, and partner selection. Addressing these challenges is crucial for successful implementation and realizing the potential advantages of the integration strategy.

Approach 3: product-based strategy

The product-based approach in the modular construction industry has emerged as a significant trend according to expert interviews. This strategy centres on the use of standardized modular building products, enhancing efficiency in the construction process as these can be replicated across projects. The financial benefits of this approach are highlighted by the potential for significant cost savings. By using standardized modules, waste is minimized, and production processes optimized, leading to reduced overall costs since [11].

> *"We have shifted our focus to developing our own standardized modular building products that can be replicated across projects. This allows us to streamline our construction processes and achieve greater efficiency in house." [Developer A]*

This quote highlights the shift in focus towards standardized modular products as a way to improve efficiency in construction. By developing standardized products, developers can reduce design and manufacturing time, resulting in faster project delivery. Another key aspect is quality control. The application of identical modules across projects ensures consistency and upholds high standards [10]. This systematic quality assurance is facilitated by the uniformity of standardized products.

Despite its emphasis on standardization, the product-based approach does not compromise on customization. Modules can be modified according to specific project requirements, retaining the inherent speed and cost-saving advantages of modular construction [3].

Furthermore, the product-based approach presents a unique opportunity for market positioning. Offering innovative, cost-effective modular solutions enables developers to stand out in a competitive market.

In conclusion, a product-based approach provides a strategic advantage in the modular construction industry. Through standardization, developers can realize efficiency, cost savings, quality control, customization, and market differentiation. These advantages make the approach a key factor in developers' success in this field.

Integration strategy 6: integrated hierarchical firms

Integration

The integration strategy of the Integrated Hierarchical Firm in modular construction involves the vertical integration of multiple stages within the production or supply chain [9]. This integration strategy encompasses the ownership and control of design, manufacturing, and distribution processes, often with the implementation of a proprietary approach or system [9]. The following quotes provide insights into this integration strategy and its implications:

> *"We have our own architects, but sometimes we also collaborate with other architectural firms, such as in the development of the Coffee Factory. In some cases, we create sketches before starting the design process. Eventually, the project can become open source, depending on the circumstances. We also have an in-house team dedicated to development and procurement." [11]*

This quote highlights the role of collaboration and internal capabilities within the Integrated Hierarchical Firm. The firm combines its own architectural expertise with external collaborations when needed, enabling flexibility and the utilization of diverse perspectives. The firm also emphasizes development and procurement as key functions within the integration strategy, showcasing the importance of internal resources and capabilities.

The specific integration strategy of the Integrated Hierarchical Firm allows for several advantages. Vertical integration enables cost reduction through the "elimination of intermediaries and streamlining of operations" [11]. The firm can allocate resources more efficiently, manage inventory effectively, and achieve economies of scale. Moreover, owning and controlling multiple stages of the production process allows for better quality control and consistent application of the firm's proprietary system [1]. This enhances the firm's ability to deliver high-quality products and maintain a competitive edge in the market.

The Integrated Hierarchical Firm promotes improved coordination and communication among different departments or stages within the organization. This facilitates efficient decision-making and enables a faster response to market changes or customer needs [1]. The firm's vertically integrated structure and proprietary system create a competitive advantage by offering unique products or services that are challenging for competitors to replicate [1]. This can act as a barrier to entry for potential competitors, protecting the firm's market position.

Furthermore, vertical integration helps mitigate risks associated with external factors, such as supply chain disruptions, price fluctuations, or regulatory changes [1]. By owning and controlling multiple stages of the supply chain, the firm has greater control over these factors and can adapt more effectively to challenges.

The Integrated Hierarchical Firm represents a new generation of industrialized construction firms that redefine the traditional business model of construction through horizontal, vertical, and longitudinal integration. The firm's structure as an integrated hierarchical entity allows for control over product architecture and processes. By conducting construction activities within a central offsite factory, the firm ensures coordination and efficiency in design, manufacturing, transport, and assembly.

Longitudinal continuity is achieved through the development of a technical building system or platform that evolves over time. This platform allows the firm to embed organizational knowledge and release updated versions of the system. The firm maintains long-term partnerships within the supply chain rather than relying on competitive bidding for procuring products that are not built in-house [12].

Examples of the Integrated Hierarchical Firm in modular construction include Listerbuildings. This firms is specialized in the delivery of housing and use repeatable modules to scale across the market. They establish long-term partnerships within the supply chain and continuously develop and evolve their technical building systems to enhance their competitive advantage. However, all of their operational segments have a separate entity under the same group to ensure that each module within the system remains profitable.

These examples illustrate the role of the real estate developer within the Integrated Hierarchical Firm. The developer plays a pivotal role in shaping the design principles, manufacturing processes, and supply chain partnerships within the firm. By leveraging internal capabilities and collaborating with external architectural firms, the developer contributes to the development and procurement functions of the integrated hierarchical entity.

Mechanism

Value Proposition Mechanisms:

Target Markets: The Integrated Hierarchical Firm identifies specific target markets based on the unique characteristics and requirements of its products and services. This involves understanding customer needs, market trends, and potential demand. By focusing on specific market segments, the firm can tailor its offerings and marketing strategies to meet customer expectations effectively.

Products and Services: The firm develops and offers a range of products and services that align with its target markets. These offerings are designed to address customer needs and provide innovative solutions. The products and services may include modular housing units, prefabricated components, or specialized construction systems. The firm's proprietary system and expertise in design, manufacturing, and assembly enable the delivery of high-quality and customizable solutions.

Revenue Model: The Integrated Hierarchical Firm establishes a revenue model based on its product and service offerings, as well as its value proposition. This may involve pricing strategies, subscription models, licensing fees, or project-based contracts. The revenue model is closely tied to the collaboration and integration of the firm's own system within the vertical integration structure.

Operating Model Mechanisms:

Value Chain: The integrated hierarchical firm optimizes the value chain by aligning the various stages of design, manufacturing, and distribution within its own system. This ensures smooth coordination, efficient resource allocation, and seamless flow of activities. By controlling multiple stages, the firm can achieve cost savings, quality control, and improved overall performance.

Organization: The organization structure of the Integrated Hierarchical Firm is characterized by vertical integration, allowing for in-house control and management of key processes. The firm may have dedicated teams or departments responsible for design, manufacturing, logistics, and assembly. This organizational structure enables streamlined communication, better coordination, and faster decision-making, leading to enhanced efficiency and productivity.

Cost Model: The firm's cost model is influenced by the vertical integration and proprietary system. By eliminating intermediaries and optimizing internal processes, the firm can reduce costs and achieve economies of scale. The cost model includes considerations such as material sourcing, manufacturing efficiency, logistics, and assembly. Effective cost management is crucial to ensure competitiveness and profitability.

Examples of these mechanisms in action within the Integrated Hierarchical Firm can be seen in companies that develop modular housing solutions. They identify specific target markets, such as affordable housing or sustainable construction, and offer a range of modular housing units tailored to those markets. The revenue model may involve selling or leasing the modular units directly to customers or partnering with developers for large-scale projects.

In terms of the operating model, the firm vertically integrates design, manufacturing, and assembly processes within its own system. It establishes dedicated teams or departments for each stage, ensuring effective coordination and seamless execution. The cost model focuses on optimizing material sourcing, manufacturing efficiency, and logistics to achieve cost savings and maintain competitive pricing.

These mechanisms collectively contribute to the value proposition and operating model of the Integrated Hierarchical Firm, allowing it to deliver innovative, high-quality products and services to target markets while ensuring efficiency, control, and cost-effectiveness throughout the value chain.

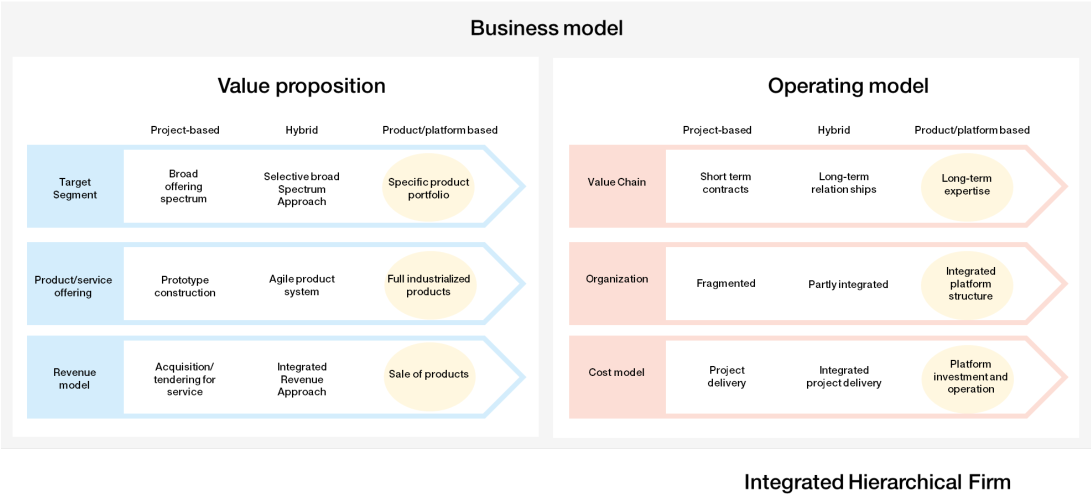


Figure 24: Business model and mechanisms of a Integrated Hierarchical Firm

Drivers and challenges

Main Drivers of the Integrated Hierarchical Firm in modular construction:

1. *Control and Quality:* One of the primary drivers of the Integrated Hierarchical Firm is the desire for greater control over the entire production process, from design to manufacturing and assembly. By owning and controlling multiple stages, the firm can ensure consistency, quality, and adherence to its proprietary system. This control enables the firm to deliver products and services that meet high-quality standards and customer expectations.
2. *Synergies and Efficiency:* Vertical integration within the Integrated Hierarchical Firm creates opportunities for synergies and increased efficiency. By integrating design, manufacturing, and assembly processes, the firm can streamline operations, optimize resource allocation, and achieve economies of scale. This integration reduces the reliance on external suppliers and intermediaries, leading to cost savings and improved overall performance.
3. *Innovation and Differentiation:* The ability to develop and implement a proprietary system is a driver for the Integrated Hierarchical Firm. This system acts as a source of innovation and differentiation, allowing the firm to offer unique products and services that stand out in the market. The firm's ability to continuously innovate and improve its proprietary system gives it a competitive advantage and positions it as a leader in the industry.

Challenges faced by the Integrated Hierarchical Firm in modular construction:

1. *Investment and Capital Requirements:* Establishing and maintaining an Integrated Hierarchical Firm requires significant upfront investment and ongoing capital. Building and operating manufacturing facilities, developing a proprietary system, and ensuring skilled personnel can be costly. Securing the necessary funding and managing financial resources effectively are challenges that the firm must address.
2. *Complex internal Supply Chain Management:* While vertical integration offers benefits, managing a complex supply chain within the firm's own system can be challenging. Coordinating design, manufacturing, and assembly processes, as well as sourcing materials and components, requires robust supply chain management capabilities.

Ensuring timely delivery, maintaining quality standards, and managing potential disruptions are key challenges to overcome.

3. *Adaptability and Flexibility:* The Integrated Hierarchical Firm needs to balance the benefits of control and standardization with the need for adaptability and flexibility. As market demands and customer preferences evolve, the firm must be able to adjust its offerings and system accordingly. Balancing customization with standardized processes and components can be a challenge, as the firm strives to meet diverse customer needs while maintaining efficiency and cost-effectiveness.

4. *Market Acceptance and Education:* Educating the market about the benefits and advantages of the Integrated Hierarchical Firm's approach can be a challenge. Modular construction and vertical integration may still be relatively new concepts in some markets, requiring efforts to raise awareness and overcome potential resistance or skepticism. Demonstrating the value proposition and building trust among customers and stakeholders are ongoing challenges that the firm must address.

By addressing these challenges and leveraging the main drivers, the Integrated Hierarchical Firm can unlock the full potential of its integrated approach in modular construction. Effective management of resources, supply chain, adaptability, compliance, and market acceptance are essential for success in this dynamic industry.

Cross-approach Analysis

In this section, the cross-approach analysis assesses the outcomes derived from three distinct approaches, aiming to compare the main themes identified in each approach. The focus is primarily on the findings from the cross-study, which delve into the integration strategies utilized for modular construction, the mechanisms implemented by real estate developers, and the underlying drivers and challenges associated with these aspects.

Common Goals and Diverse Approaches

While the integration strategies across the three main approaches differ in their specific implementation, they share some common goals and principles. Collaboration, efficiency, and control are key themes across all approaches, albeit with varying degrees of emphasis.

Project-based approaches prioritize collaboration among multiple entities to deliver customized solutions for individual projects. Hybrid-based approaches strike a balance between flexibility and standardization, leveraging collaborations and partnerships to achieve economies of scale. Product-based approaches focus on vertical integration and control, aiming to optimize efficiency, quality, and market differentiation.

Despite their differences, all approaches aim to harness the benefits of modular construction, such as cost savings, quality control, and enhanced productivity. They reflect different strategic choices and organizational priorities, offering companies flexibility in aligning their integration strategies with their unique circumstances and goals.

Integration strategies

In a project-based approach, integration strategies primarily revolve around ensuring effective coordination of various actors involved in the project for the duration of its lifecycle. There's often a high degree of vertical integration since the developer oversees each project phase, from inception to completion. However, the transient nature of projects in this approach poses challenges for longitudinal integration since long-term customer relationships aren't typically the focal point. As for horizontal integration, its application might be minimal because the focus remains concentrated on individual projects, reducing the need for diversification across different markets.

In the Hybrid-based approach, developers can leverage both vertical and horizontal integration. They control multiple stages of the real estate development process (vertical integration), while also diversifying their activities across different project types or markets (horizontal integration). Longitudinal integration also becomes more feasible as developers manage a diverse portfolio and can offer extended services like property management. Nevertheless, striking a balance between these integration strategies can be complex, as developers need to ensure their diverse operations align with overarching strategic goals.

Contrastingly, in a product-based approach, the main integration strategy leans towards vertical integration. By establishing a structured and replicable development process, the developer manages all stages, from planning to selling, thereby ensuring cost-efficiency and quality control. While this approach allows for more control and consistency, it may reduce the flexibility to adapt to changing market conditions quickly. Horizontal integration may be less prominent as the focus is on producing a specific product, and likewise, longitudinal integration could be limited, given the emphasis on the product rather than extended customer relationships. To conclude, all three approaches can incorporate different integration strategies, the degree and manner in which they do so largely depends on their inherent characteristics and objectives.

Mechanism

In terms of integration mechanisms, each approach employs distinct methods, yet there are areas of overlap. For instance, the project-based approach centres around effective management of individual projects, often facilitated by comprehensive project management methodologies and contractual agreements with stakeholders. This is in stark contrast with the product-based approach, which focuses on consistency and efficiency through standardization of processes and systems.

However, the Hybrid-based approach presents a blend of these strategies. It shares with the project-based approach the need for robust project management and the strategic formation of partnerships but also aligns with the product-based approach in its utilization of standardized strategies for certain tasks. It bridges these two strategies by leveraging strategic planning and robust communication to coordinate both unique and recurring elements of various projects.

In terms of similarities, all approaches require strong mechanisms of coordination, either at a project or organizational level, to ensure smooth operations. Furthermore, technology is an essential tool across all approaches, whether for managing individual projects, coordinating across diverse operations, or enabling design and production standardization.

Interestingly, each approach deals differently with flexibility and control. The project-based approach, with its focus on individual projects, allows the most flexibility to adapt to market changes or specific project needs but may suffer from less overall control. The product-based approach, on the other hand, emphasizes control through standardized processes but may struggle to adapt quickly to new market trends or project-specific requirements. The Hybrid-based approach tries to balance these two aspects, offering a degree of both flexibility and control depending on the specific mix of strategies employed.

In summary, while the project, Hybrid, and product-based approaches each have their unique mechanisms for achieving integration, they share common elements. However, the way they balance flexibility and control, along with their reliance on technology, presents both contrasting and complementary aspects.

Drivers and challenges

In analysing the three main approaches in real estate development - project-based, Hybrid-based, and product-based - it becomes evident that each strategy carries its unique characteristics, benefits, and challenges, which offer varying levels of flexibility and adaptability to market conditions.

The project-based approach, for instance, is inherently flexible to market demands due to its focus on one-off, unique projects. This strategy allows developers to adapt their offerings based on specific location, design, or market trends. Each project's uniqueness, either in terms of design or location, serves as a primary selling point, attracting potential investors and buyers. However, the project-based approach is not without its challenges, as each project's unique characteristics can also result in uncertainties in cost, time, and quality, thus increasing the risk factor.

In contrast, the product-based approach may seem rigid, given its focus on standardized, scalable developments. Developers opting for this strategy invest heavily in a solid organizational infrastructure, manufacturing, and fabrication lines, allowing them to replicate successful projects across different locations efficiently. The primary advantage here is predictability - with standardized units, developers can calculate potential costs, returns, and construction timelines more accurately. However, this approach lacks the flexibility of the project-based approach, as changing customer preferences or unique site conditions might require costly alterations to the established production process.

Situated in between these two approaches is the Hybrid-based approach. By combining elements from both the project and product-based strategies, developers following this approach enjoy the benefits of diversification. This approach serves as a buffer against market fluctuations and allows developers to remain profitable across different types of projects. However, the major challenge lies in resource allocation and coordination, which requires efficient management to handle the increased complexity of managing different project types simultaneously.

In essence, while each of these approaches has its distinct drivers and challenges, they all share the fundamental goal of creating value through real estate development. Their chosen strategies dictate their adaptability to changing market trends, their ability to manage and allocate resources, and their risk management capabilities. However, regardless of the approach, navigating the uncertainties inherent to real estate development remains a common thread that ties them all.

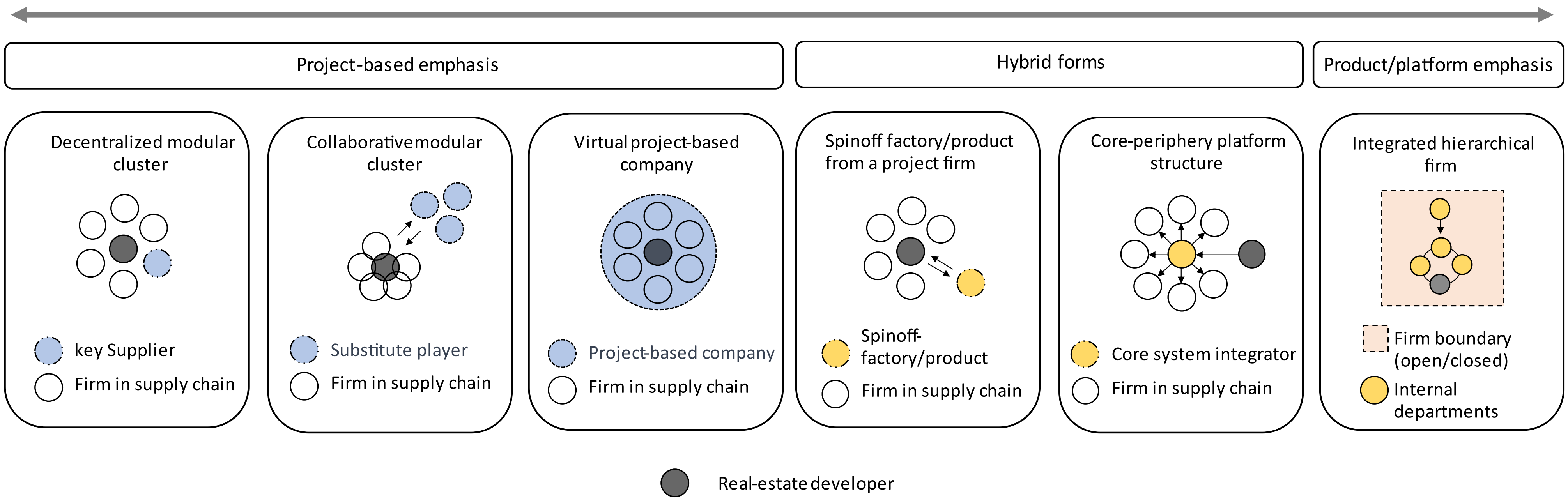


Figure 25: spectrum of integration strategies (inspired by Hall, 2018)

Findings conclusion

In conclusion, this comprehensive analysis explores how real estate developers integrate modular construction within their businesses. By addressing the main research question and sub-questions, the findings have gained valuable insights into the challenges, drivers, integration strategies, and mechanisms employed by developers in the modular construction industry.

The findings reveal a wide spectrum of integration strategies available to real estate developers in modular construction, as illustrated in Figure 25 on the previous page. These strategies range from project-based approaches such as the Decentralized Modular Cluster, Collaborative Modular Cluster, and Virtual Project-Based Company, to Hybrid-based approaches like the Spinoff Factory and Core-Periphery Platform Structure, and finally, product-based approaches exemplified by the Integrated Hierarchical Firm. The spectrum illustrates the diversity and flexibility of approaches that developers can adopt to integrate modular construction within their operations.

Figure 26 further highlights the wide spread of mechanisms employed by different developers. These mechanisms encompass both value proposition mechanisms and operating model mechanisms. Value proposition mechanisms focus on target markets, product and service offerings, revenue models, and the value chain. Operating model mechanisms pertain to the organization's structure, the value chain, and the cost model. By leveraging these mechanisms, developers can create synergies, enhance efficiency, and achieve their integration objectives.

Addressing the sub-question on challenges and drivers, this study identified the main drivers include a focus on innovation, resource and support, transition to industrialized construction, cost savings and efficiency, alignment with business philosophy, and strategic product positioning. On the other hand, challenges involve managing supply and demand, educating the supply chain, addressing unprofitability, navigating regulatory complexities, and financing, making trade-offs and adaptability, and overcoming high initial investment requirements.

To mitigate these challenges, developers can adopt suitable integration strategies. Project-based approaches allow for decentralized or collaborative clustering, promoting collaboration and flexibility. Hybrid-based approaches facilitate the establishment of spinoff factories or core-periphery platform structures, enabling innovation and resource optimization. Product-based approaches emphasize the development of integrated hierarchical firms, enabling vertical integration and control over multiple stages of the production process.

In conclusion, real estate developers in the modular construction industry have a wide range of integration strategies and mechanisms at their disposal. By understanding the challenges, drivers, and mechanisms outlined in this analysis, developers can make informed decisions about how to effectively integrate modular construction within their businesses. The findings provide a valuable resource for developers seeking to optimize their operations, enhance efficiency, and leverage the benefits of modular construction in the evolving construction landscape.

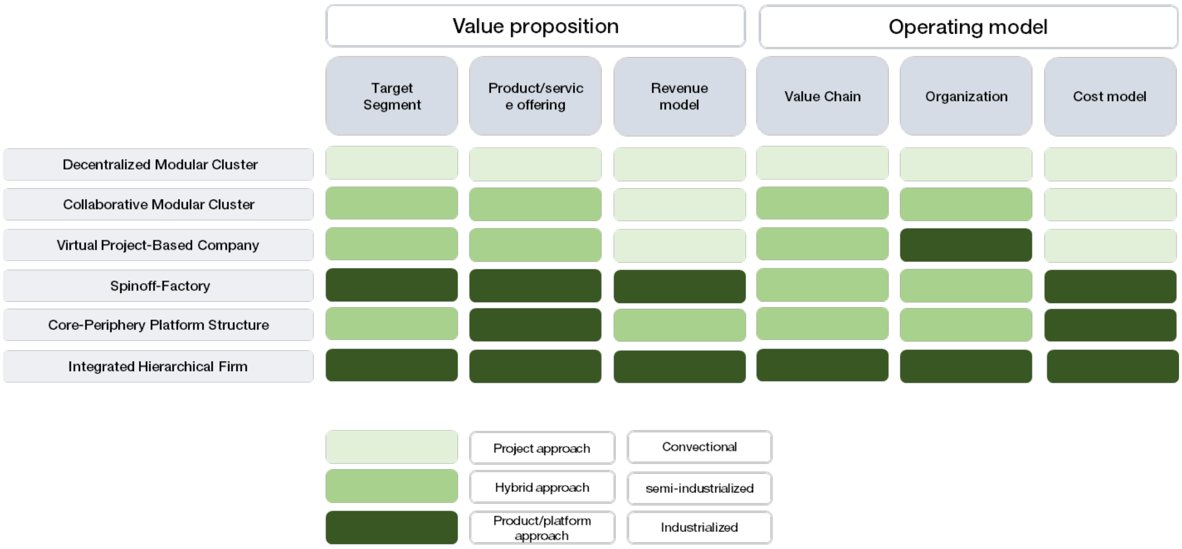


Figure 26: Overview of mechanisms of each strategy

5

Discussion and recommendations

General Discussion

This thesis investigates the integration of modular construction in real estate development, specifically focusing on project developers. Ongoing reorganization efforts present opportunities for firms to deliver buildings in a more integrated manner. The process of integration can be achieved through firms that are integrated vertically and horizontally, or by forming long-term partnerships focused on longitudinal integration (Levitt, 2007; Sheffer, 2011; Hall, 2020). The spectrum of integration spans from fragmented modular clusters to integrated hierarchical firms. However, the findings demonstrate that increased integration does not necessarily guarantee better outcomes, as different levels of integration come with their own set of benefits and challenges. Below the 6 strategies are illustrated (Figure 25).

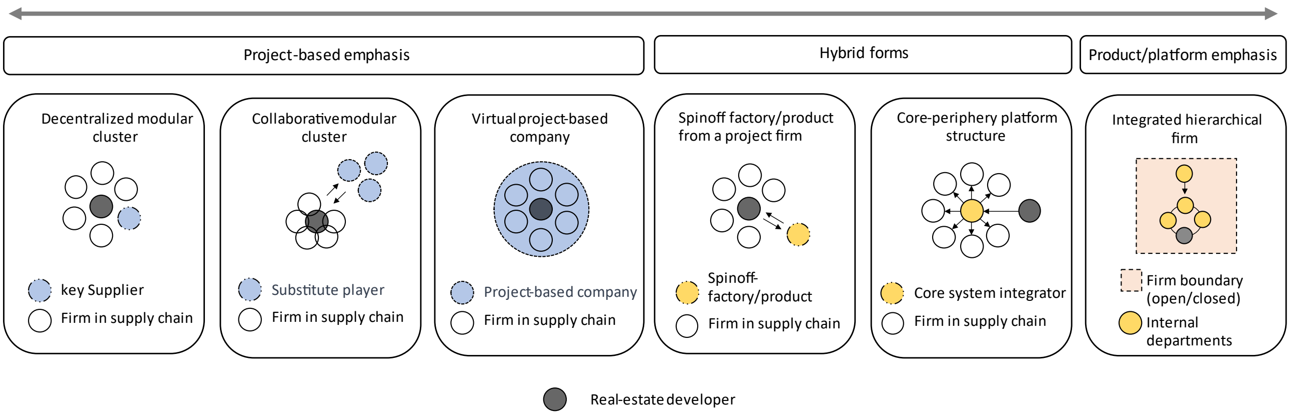


Figure 27: spectrum of integration strategies (inspired by Hall, 2018)

Suitable Approaches for Integration

Looking at the six re-organization strategies, this study presents two extreme ways of integration either project-based or product-based and in between there are hybrid forms. This demonstrates that there are a multitude of way in which real estate developer can integrate modular construction. All efforts represent a form of partial mirroring or statistically mirror breaking as also seen in the construction literature on other stakeholders' groups (Colfer and Baldwin, 2016; Hall et al, 2020). This highlights that, similar to other stakeholder groups like contractors or architects, developers have multiple ways to integrate modular construction. These diverse approaches can be seen as mirrors that partially reflect or deviate from traditional construction development practices. The appropriateness of each strategy depends on factors such as client types, product characteristics, and economic conditions. By considering these factors, real estate developers can choose the most suitable strategy for integrating modular construction that fits within their firms' scope. To deepen the discussion, the three distinctive strategic approaches and unique mirror-breaking forms employed by each of the six strategies are explored.

Project-Based Strategies for Integrating Modular Construction

The research presents three project-based strategies for integrating modular construction. The first strategy reflects the conventional organizational mirroring, functioning within decentralized modular clusters, as proposed by Colfer and Baldwin (2016). Despite challenges related to effective mediation, it demonstrates the potential of successful integrating modular construction while maintaining the existing organizational structure. For example, traditional developers enable modular construction though informal project-based mechanisms such as early involvement. This strategy is adopted by project developers who have a diverse project portfolio due to their market positioning. The second strategy leans towards a partial mirroring approach, embracing collaborative modular clusters through Supply Chain Integration Practices (SCIPs), and offering project management capabilities at the expense of potentially increased overhead costs and transparency risks (Hall et al, 2020). The third strategy emphasizes virtual, project-based firms, utilizing mirroring-breaking strategies facilitated by digitization and relational formal contracts. Despite initial costs and potential disruption to the business model, this approach promotes a more integrated model (Colfer and Baldwin, 2016). Each strategy highlights unique challenges but provides distinctive insights into the systematic integration of innovation in project-based organizations, with the critical role of real estate developers in navigating these complexities emphasized. While project-based models may offer limited advantages to other stakeholders like architects and contractors (Whyte and Levitt, 2011; Lessing et al., 2015l Hall et al, 2020), they seem particularly beneficial for developers. With these models, developers retain control and utilize their industry expertise, allowing them to adapt flexibly to market fluctuations without being constrained to a particular product.

Hybrid-Based Strategies for Integrating Modular Construction

Second, this research presents two hybrid-based strategies for integrating modular construction. The Spinoff Factory strategy encourages innovation and entrepreneurship within organizations by facilitating the creation of new market products in a controlled environment (Hall et al, 2020). This strategy challenges strict mirroring and promotes cross-functional collaboration (Lobo and Whyte, 2017). By expanding knowledge boundaries and leveraging supply chain integration practices, it offers a dynamic and more product-based alternative to traditional project-based approaches (Hall, 2018). Second, the Core-Periphery Platform Structure strategy involves real estate developers partnering with core platforms to integrate standardized production processes while maintaining design flexibility. This enables collaborative and efficient modular construction (Lessing et al., 2015; Lasi et al., 2014). This approach aligns with the literature highlighting the transformative potential of digitalization in reshaping project management. This strategy is best suited for organizations that wish to maintain agility and flexibility while dealing with a wide variety of projects. It's especially beneficial for those who are keen on harnessing the power of digital systems integration, mass customization, and have a network of reliable partners. However, it requires patience for long-term co-creation processes and a willingness to work within the offerings of partner organizations (Hall et al., 2020). While these hybrid-based strategies offer innovative solutions, their implementation may vary based on project complexity, scale, and desired outcomes. It is essential to further investigate the viability and effectiveness of these strategies, considering variations in organizational structures, collaborations, and the specific context of the construction industry.

Product-Based Strategies in Modular Construction

Finally, product-based strategies in modular construction involve the Integrated Hierarchical Firm, which adopts a supply-push paradigm and maintains control over product development and processes (Sheffer, 2015; Hall et al., 2018). Real estate developers such as Lister Buildings exemplify this approach in driving their modular construction efforts. The adoption of industrialized construction and modularization by the Integrated Hierarchical Firm represents a strategic mirror-breaking strategy, pushing the boundaries of technical change (Hall, 2018). However, the presence of independent clusters within the organization raises questions about the extent of mirror-breaking and the fluidity of integration across boundaries. Addressing capital requirements, supply chain management, and regulatory compliance is crucial for the successful implementation of mirror-breaking strategies in product-based approaches. Further research is needed to explore the nature and implications of these internal clusters on mirror-breaking strategies.

Characteristics of distinct approaches

It is vital to note that the processes of re-organization and re-modularization are fluid in nature as also explained by Daniel Hall (2018). These processes involve restructuring the way work is organized and assigning new functions to different components within the company. One important aspect of this process is understanding how these new components should interact with each other. It requires designing interfaces or connections that facilitate effective communication and collaboration between different teams or departments.

This study shows that for real estate developers every reorganization strategy undertaken, it is imperative to guarantee the uninterrupted functioning of the business. The findings suggests that during an unstable economic climate, firms tend to adopt a more project-based approach, whereas in a stable climate, firms move towards more continuity and product orientation. As significant capital investments are required not only for establishing product or platforms but also for adapting to sudden shifts in demand. Similar to industries using customized injection moulding, new designs necessitate costly retooling (Berman, 2012). Current studies indicate a shift from project-based orientation to product or platforms- based, utilizing modular components for delivery, like software or mobile phone updates (Hall et al., 2022). This approach allows for ongoing enhancement of organizational knowledge and long-term supply chain partnerships, moving away from competitive project bidding (Hall et al., 2020). However, findings from real estate developers suggests that the benefits of project-specific solutions can be harnessed within this ongoing shift, focusing on the reorganization and integration of technologies at an organizational level. This enables various types of integration, such as longitudinal, vertical, or horizontal. For example, virtual project-based firms utilize interfirm project boards for integrated control, fostering lasting partnerships with supply chain collaborators but within a project-based environment. Nonetheless, this presents an avenue for future research. It would be compelling to examine how product-based strategies might navigate and thrive in unstable or sluggish economic climates, capitalizing on inherent benefits while mitigating potential drawbacks, with particular emphasis on understanding how hybrid strategies may already capitalize on this.

Comparison with Other Stakeholders

In the construction industry, we often draw comparisons with the automotive industry. In terms of system integration, however, these comparisons are stark in their discrepancies. The decentralized organizational model in construction is the essence of this differences, suggesting weaker system integration in construction as compared to automotive (Dubois & Gadde, 2002). At the center of the construction process, we find system integrators, namely the architect who assumes the design role, and the main contractor responsible for the actual construction. However, these pivotal roles often present as weak integrators, coordinating many trades on site with a relatively small management team that can't closely monitor all work (Hall, 2018). This contrasts with the more centralized model of the automotive industry, where the system integrators have a stronger role, specifying exactly how tasks should be performed (Winch, 2014).

In traditional construction projects, this reliance on craft administrations and codes of practice for how work should be done often means the process is largely left to the decentralization of the supply chain. Thus, you find many low-bid firms in the supply chain coordinating with each other, with the system integrator loosely assembling the overall structure. While such a model can function adequately for standard projects, challenges arise when variables change (Dubois & Gadde, 2002). Conversely, in modular construction, the importance of system integration is more pronounced due to the need for efficient coordination of components and processes. In this regard, a strong system integrator leveraging their knowledge, skills, and networks becomes critical to facilitating such coordination (Sheffer, 2011).

As Hall (2018) points out, the traditional construction model often views the main contractor as a weak integrator. However, as the complexity of the integration process escalates in modular construction, this role is amplified or supplanted by digital system integrators. In this lies the interest in considering the role of the real estate developer as a potential system integrator. Developers are known to manage a bond of relationships between different stakeholders and could potentially wield a more dominant role, bridging the gap between the architect and main contractor. In future studies it would be interesting to explorer, how strong or weak they may function as system integrators.

Limitations of research method

While the discussion has brought forth the limitations and ambiguity surrounding the role of the real estate developer especially as a strong or weak system integrator, the research method and approach itself also entail some constraints that ought to be acknowledged for a thorough understanding of the results.

Primarily, the research emphasis is on distinct strategies and methods associated with modular construction within the realm of real estate development. This focus inherently narrows down the research breadth, potentially hindering its applicability to different stakeholders or contexts. As such, caution is warranted when extrapolating these findings beyond the specified context.

Moreover, the insights presented were derived from a combination of theoretical frame of reference and empirical data. The empirical data was collected from a finite number of expert interviews, which may not encompass the entire spectrum of possibilities and divergences inherent in industrialized construction. Information regarding the various strategies was relatively limited, an issue that individual case studies for each strategy might have mitigated. Therefore, the insights presented may not fully capture the complex nature of modular construction within real estate development.

The study also leans heavily on self-reported data from real estate developers. The use of such data often introduces biases or limitations due to inaccurate recollection or personal perceptions, potentially undermining the reliability of the gathered information and, consequently, the conclusions drawn from it.

Finally, the timing of the research coincides with a period of significant economic volatility, which could have influenced the outcomes. The research span saw construction and labour costs rise significantly alongside concurrent interest rate hikes - factors that may have considerably affected some industry business models. Unfortunately, this economic backdrop was not factored into the research, thereby further limiting the applicability of the findings. As such, the research outcomes should be understood within this specific economic period and may not remain as relevant under different economic conditions.

Implications

The exploration of modular construction strategies within the realm of real estate development brings forth significant implications. Not only does it benefit practitioners in the field, but it also carves out a path for further academic investigation.

A key implication of this research is the detailed insights it offers on the myriad strategies that real estate developers can employ to incorporate modular construction into their business models. Through in-depth investigation of these approaches, the study fills a critical void in existing literature, serving as a navigational aid for real estate developers aspiring to harness the advantages of modular construction.

Moreover, the study emphasizes the importance of strategy selection tailored to the unique contexts and objectives of individual development projects. The three categories of strategies -

project-based, product-based, and Hybrid-based - need to be carefully weighed and considered, underscoring that there is no universally optimal approach in this diverse field. This acknowledgment of the necessity for adaptability and nuanced strategy selection serves as a crucial takeaway for developers.

Another noteworthy aspect of the study is the exploration of the mirroring, partial mirroring, and mirror-breaking strategies. The research delves into their potential advantages and challenges, offering developers a comprehensive spectrum of their options. With this knowledge, they are better equipped to make decisions that align with their specific requirements and constraints, effectively enhancing the successful integration of modular construction.

Finally, the research highlights the pivotal role of real estate developers as the drivers of successful implementation of modular construction. It opens a underexplored field in the literature for the integration of modular methods within the broader context of industrialized construction.

These implications not only provide actionable guidance for real estate developers but also present a fruitful area for future academic exploration. As such, the research helps to inform and shape the future trajectories of both practice and academic study within the field of modular construction in real estate development.

Future studies

The research presented provides crucial insights into the integration strategies of modular construction within real estate development. However, acknowledging the inherent limitations enhances our understanding of these findings and presents potential areas for future research.

One fundamental limitation of the study is its focused scope, specifically examining strategies and approaches to modular construction within real estate development. Although this focus allows for in-depth exploration, it potentially restricts the study's applicability to broader contexts or other stakeholders in the industry. Moreover, while this study identified six strategies for integrating modular construction, it is important to note that there could potentially be additional strategies that have not been identified yet. Although the insights garnered offer valuable perspectives, they may not entirely capture the extensive range of possibilities inherent in modular construction, particularly within real estate development.

A second limitation lies in the omission of an in-depth examination of the financial and economic implications of the various strategies. These factors can profoundly influence decision-making in real-life scenarios. The lack of focus on these aspects might limit the practical applicability of the research findings to some extent.

Lastly, the timing of the research coincided with a period of significant economic fluctuation, including a sharp rise in construction and labour costs alongside increased interest rates. These conditions could have significantly impacted some business models within the industry. However, this economic context was not accounted for in the research, which may limit the applicability of the findings under different economic conditions.

In conclusion, recognizing these limitations is crucial for interpreting the research's findings accurately and provides a platform for future studies. Despite these limitations, this study contributes significantly to our understanding of the integration strategies real estate developers employ in modular constructions.

Recommendations for real estate developers

The integration strategies identified by the interviewees provide valuable insights into the practical considerations and potential improvements that can be made within the modular construction industry. As a result, I have identified sex key steps that every real estate firm should consider, regardless of their delivery strategy, when adopting modular construction. The following discussion outlines the implications for real estate developers.

i. Embrace an industrialized approach

Integrating a hybrid approach, which combines elements from both project-based and product-based strategies, allows for a greater degree of flexibility, adaptability, and efficiency. This new strategy brings together the benefits of both approaches while mitigating their limitations, thus providing a balanced response to the varying needs of the construction industry. The flexibility and adaptability offered by this strategy enable developers to respond to unique project requirements while benefiting from the efficiencies gained from standardized production.

ii. Create a Product Strategy

A well-defined product strategy is essential for developers to maximize the potential of modular construction. Especially for more traditional companies who not always have a clearly defined strategy. By identifying target markets and understanding their specific needs, developers can tailor their modular construction offerings. This not only allows for better resource allocation but also drives innovation within the industry. Developers should be aware of their catalytic position. A focused product strategy enables developers to remain competitive and adapt to market changes while effectively addressing customer needs.

iii. Develop Unique Product Offerings

Developing unique product offerings can help developers differentiate themselves from traditional competitors and capture a larger market share. By incorporating innovative design elements, materials, and construction techniques, modular construction companies can offer solutions that are more efficient, sustainable, and cost-effective which could help by winning a tender for example.

iv. Optimize Design for Factory Production and Logistics

One of the primary advantages of modular construction is the ability to streamline the manufacturing process through factory production. The role of the real developer is to rethink their design and construction requirements to fit within standardized production and logistics. Optimizing designs for factory production can significantly reduce construction time and cost, while also minimizing waste and environmental impact. This involves considering assembly line processes, transportation, and on-site installation during the design phase. By investing in the research and development of modular design optimization, construction companies can achieve greater economies of scale and enhance the overall efficiency of their projects.

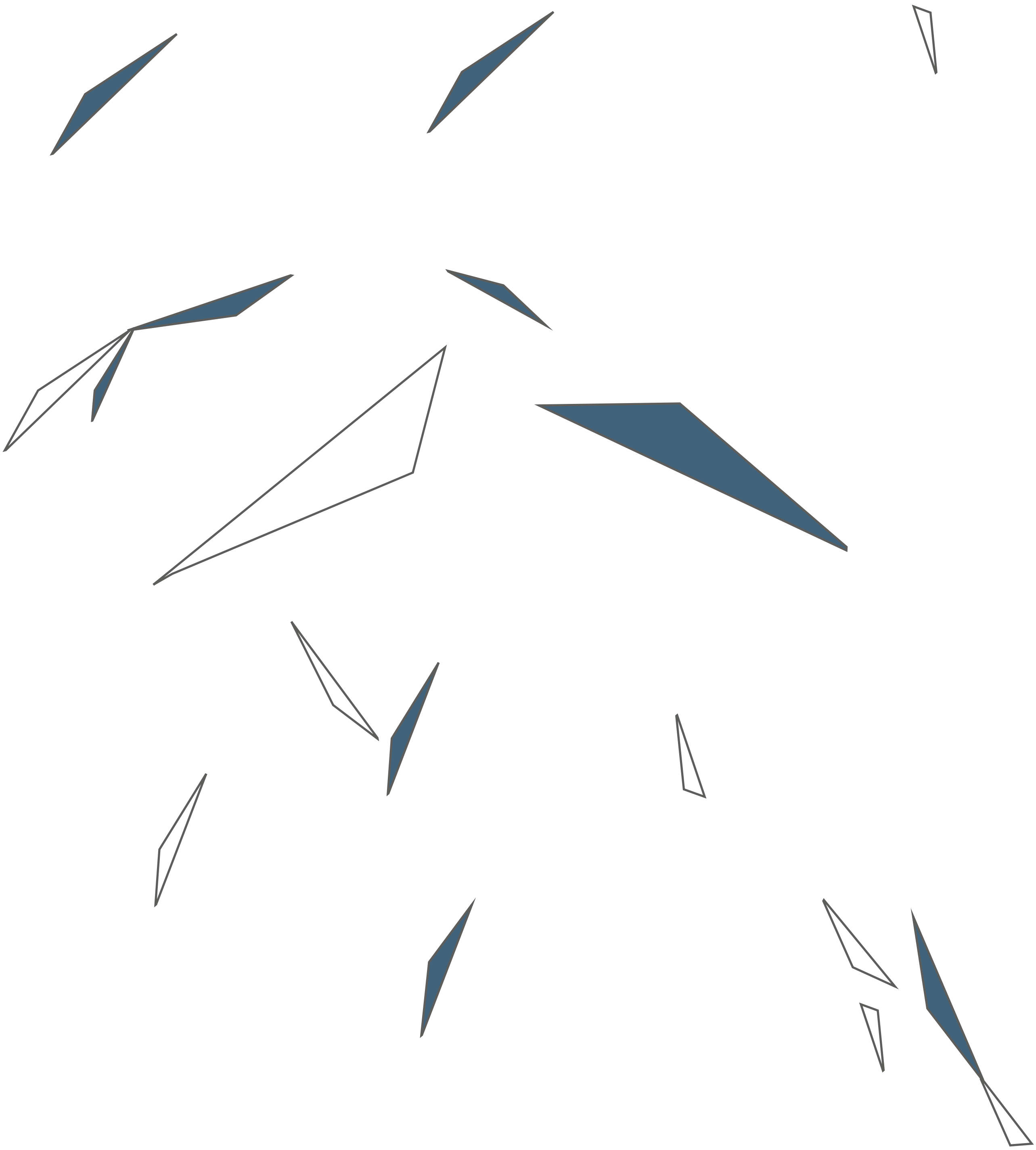
v. Build Relationships with Modular Suppliers

Establishing strong relationships with modular suppliers is essential for ensuring a reliable supply chain and maintaining high-quality standards. By collaborating with suppliers, construction companies can gain access to the latest materials and technologies while also ensuring consistent quality across their projects. Additionally, fostering partnerships with suppliers can enable construction firms to leverage the suppliers' expertise and resources, leading to improved project outcomes and increased customer satisfaction.

vi. Test Fully Modular Construction

Investing in pilot projects to test fully modular construction methods can provide valuable insights and help to refine the overall process. These projects can serve as an opportunity for developers to identify potential challenges, evaluate cost-effectiveness, and gather feedback from end-users. This iterative process allows for continuous improvement and refinement of modular construction techniques, ultimately contributing to the industry's growth and long-term success.

In conclusion, the integration strategies highlighted by the interviewees offer possibility de distil a roadmap for the modular construction industry to address current challenges and capitalize on emerging opportunities. By implementing these strategies, industry stakeholders can drive innovation, enhance efficiency, and create a more sustainable and cost-effective alternative to traditional construction methods.



6

Conclusion

Conclusion

This thesis embarks on a comprehensive exploration of strategic approaches to integrating modular construction within real estate development, with the overarching aim of promoting the widespread adoption of industrialized construction practices. The research is grounded in the main research question: *"How does and how can real estate developers strategically integrate modular construction in adopting industrialized construction?"* This inquiry is pursued through the examination of three sub-questions, informed by insights derived from 11 expert interviews with real estate developers. In doing so, this study draws upon the extensive research conducted by Daniel Hall, Jennifer Whyte, and Jerker Lessing, who have made significant contributions to the field by investigating mirror-breaking strategies for systemic innovations within the construction industry.

The research commenced by acknowledging the industry's transition from project-focused strategies to product/platform-oriented approaches. This shift is influenced by the mirroring hypothesis, which posits that an organization's structure and operations mirror its technical systems and processes. However, the construction industry currently grapples with a challenge known as the mirroring "trap," characterized by fragmentation and decentralized project organization, which hinders the recognition and harnessing of potential benefits from systemic innovations that extend beyond firm boundaries. This research does not purport that the strategies outlined are the sole methods through which companies can foster systemic innovations. It is plausible that there exist other forms yet unobserved. Nevertheless, it appears that all these strategies would likely align with the three principal approaches discussed.

The study has identified and categorized six re-organization strategies as project-based, hybrid-based, and product-based approaches. Project-based strategies offer flexibility and adaptability through decentralized modular clusters, Supply Chain Integration Practices (SCIPs), and digital contracts. Hybrid-based strategies, such as the Spinoff Factory and Core-Periphery Platform Structure, strike a balance between innovation and market demands by encouraging cross-functional collaboration and standardized production processes while maintaining design flexibility. Product-based strategies, exemplified by the Integrated Hierarchical Firm approach, involve comprehensive control over the entire product development process and pushing technical boundaries, albeit necessitating significant capital investment and robust supply chain management.

The study has delved into the challenges and drivers that influence the adoption and enhancement of modular construction strategies. Each strategy presents its own set of challenges and drivers for the adoption of modular construction. While all strategic approaches have the same goal to integrate more modular construction. The study has explored how real estate developers can play a strategic and proactive role in advancing the broader adoption of industrialized construction. Findings show that developers can act as catalysts for change by advocating for the benefits of modular construction, promoting knowledge sharing and collaboration among stakeholders, and investing in research and development to drive innovation. Additionally, developers can support industry-wide initiatives, participate in standardization efforts, and establish partnerships with modular construction suppliers and manufacturers. Embracing this strategic and proactive role enables developers to contribute to the wider adoption of industrialized construction practices, fostering efficiency, sustainability, and improved project outcomes within the real estate development industry.

In conclusion, real estate developers play a pivotal role in strategically enhancing the integration of modular construction within the industry, employing various strategies ranging from project-based to hybrid-based and product-based approaches.
Careful consideration of specific needs, market positioning, and economic conditions is paramount when selecting the most suitable strategy. By gaining a comprehensive understanding of the challenges and drivers at play, developers can make informed decisions regarding their strategic approach. This knowledge empowers them to effectively navigate the complexities involved in enhancing the integration of modular construction within their projects.

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A

Appendices

About the author

Thijs Müller, born on November 13, 1994, is a master's student with a diverse academic and professional background. Following his Bachelor's in Construction Management from Amsterdam University of Applied Sciences, Thijs has been pursuing his Bachelor in Architecture and his Master's, specializing in Management in the Built Environment both at the Delft University of Technology. His academic endeavors have been supplemented by professional roles, most recently as a Project Developer at Boelens de Gruyter and as a co-founder of Brouwer and Müller Projects.

Throughout his Master’s program, Thijs has focused on the digitalization, sustainability, and aesthetics of the built environment, expanding his professional network and contributing to various projects. His Master’s thesis, 'Navigating the Modular Shift: Integration Strategies for RE Developers,' reflects his passion for the built environment and showcases his understanding of real estate development and urban planning. With the completion of his Master’s degree, Thijs aims to fully focus on project development, leveraging his comprehensive skills and experience to contribute to the future of the built environment.

Consent letter and form

Delft, 5 February 2022

Dear Sir / Madam,

I hope this letter finds you well. I am writing to extend an invitation for you to participate in a research study focused on the integration of modular construction techniques in the real estate development sector. Your expertise and insights would be invaluable in contributing to the understanding of how real estate developers can effectively integrate modular construction into their business practices.
The objective of this research study is to bridge the existing gap in literature by exploring the role of project developers in the integration of modular construction. By focusing on the real estate sector, we aim to analyze the challenges and drivers, integration strategies, and the mechanisms employed by developers to successfully integrate modular construction. The study aims to achieve the following research objectives:

1. Analyse integration strategies that real estate developers employ to mitigate the identified challenges.
2. Investigate the specific mechanisms, tools, resources, and partnerships that real estate developers can utilize in these integration strategies.
3. Identify the primary challenges and drivers faced by real estate developers in integrating modular construction in their businesses.

Your participation in this research will greatly contribute to achieving these objectives and advancing knowledge in the field. The study will involve conducting semi-structured interviews to gain first-hand insights from industry experts like yourself. These interviews will be used to collect empirical data and explore the integration process, challenges, drivers, strategies, and the future outlook of modular construction in the real estate sector.
The interview will revolve around the following key themes:

1. Exploring your journey towards the integration of modular construction.
2. Understanding the specific tools and strategies employed in the integration process.
3. Identifying the primary drivers and challenges encountered in your modular construction approach.
4. Gathering your views on strategies adopted by other companies in the sector.
5. Capturing your perspective on the outlook of modular construction.

Your participation will involve approximately 60 of your time, which can be conducted at your convenience. The interviews will be conducted either in person or via video conferencing, depending on your preference and availability.

Your insights and experiences will form a crucial part of this study's empirical data, contributing to the analysis and synthesis of the integration process and its implications. The research findings will be used to provide actionable recommendations for real estate developers and other stakeholders to facilitate the effective integration of modular construction.

Data collection

The de interview will be recorded for transcribing purposes. As with any activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by anonymizing the collected data, the recording will be destroyed after transcribing and the data collected will be used solely for analysis and scientific presentation and publications.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

Contact details for the corresponding and Responsible Researcher

Please get in touch with us using the information below if you have any questions about the study.

Name: Thijs Müller
Email: t.muller-2@student.tudelft.nl
Phone: +********

Thank you very much for considering this invitation. Your contribution to this research will undoubtedly advance our understanding of modular construction integration in the real estate sector.

If you would like to participate in this interview, please complete the statement below and sign it.

Sincerely,

Thijs Müller

Signatures

Participant

- ☐ I have read this form, or the form has been read to me and I agree to participate in the study.
- ☐ I agree that the interview will be audio-recorded and transcribed
- ☐ I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.
- ☐ I understand that after the research study the de-identified information I provide will be used for the thesis report, presentation, and publication
- ☐ I agree that my responses, views, or other input can be quoted anonymously in research outputs
- ☐ I would like to receive a summary of the results of the thesis at the end of the research project. For this reason, I grant permission to keep my name and address details until the end of the study.

Name of participant	Signature	Date

Researcher

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name	Signature	Date

Interview protocol

Interview Protocol for Semi-Structured Interviews with Real Estate Developers

The following protocol has been designed to guide semi-structured interviews for the purpose of gaining a nuanced understanding of the experiences and perspectives of real estate developers involved in modular construction. This method provides the flexibility to delve deeper into specific themes while maintaining enough structure to keep the conversation focused on the research objectives.

The aim is to facilitate a jargon-free conversation, ensuring that all participants share a common understanding of the terms used in the research. For this purpose, a preliminary question has been added to ensure that all participants share a common understanding of the concept of modular construction and industrialized construction.

I. INTRODUCTION

- Purpose of the interview (e.g., to gain insights into your experiences with modular construction)
- Use of semi-structured interviews (e.g., these are flexible interviews where we have a list of topics we would like to cover, but the conversation can flow naturally)
- Documentation of interview invitations and questions (e.g., all interviews are confidential and will only be used for this research project)

II. CONCEPTUAL CLARIFICATIONS

- Can you describe your understanding of the concept of modular construction? (3D modular off-side)
- How do you define the term 'industrialized construction' in the context of your work? (Industrialized construction is a strategic approach integrating supply chains, design, logistics, and customer needs in construction (Hall et al., 2022)

III. KEY THEMES

A. Exploring the Journey towards Modular Construction Integration

- Background and motivation (e.g., what sparked your interest in modular construction?)
- Decision-making process (e.g., why?)
- Implementation steps (e.g., could you briefly describe the steps you took to introduce modular construction to your company?)

B. Tools and Strategies in Modular Construction Integration

- Selection of modular components (e.g., how do you decide which parts of the building will be built off-site?) •
- Design and engineering considerations (e.g., can you tell me about any unique design features that you had to consider due to the modular approach?)
- Construction and assembly techniques (e.g., can you describe how the parts are assembled on site?)

C. Drivers and Challenges in Modular Construction Approach

- Cost considerations, Time efficiency, Quality control, and standardization (e.g., these factors often known as the Golden Triangle in project management)
- Regulatory and compliance factors (e.g., have there been any laws or regulations that have affected how you use modular construction?)

D. Views on Strategies Adopted by Other Companies

- Industry best practices (e.g., are there any strategies used by other companies that you've found helpful or impressive?)
- Collaborative approaches (e.g., have you worked with other companies on any modular construction projects?)
- Lessons learned (e.g., looking back, is there anything you would have done differently?)

E. Outlook of Modular Construction

- Anticipated advancements and innovations (e.g., where do you see the future of modular construction heading?) •
- Potential opportunities and limitations (e.g., what do you see as the biggest opportunities and challenges for modular construction in the future?)
- Projected impact of modular construction on the construction industry (e.g., what effect do you think the rise of modular construction will have on the wider construction industry?)

IV. Detailed Discussion (for round two)

Interviewee's experiences and insights within each strategy (e.g., do you have any specific stories or examples that come to mind when discussing this strategy? (Explain and show approach project-based, hybrid-based, and product-based)

V. Conclusion

- Appreciation for their contribution (e.g., thank you so much for your time and insights)
- Opportunity to add any additional points or aspects not mentioned (e.g., is there anything else you would like to add or any other topics you think we should cover?)