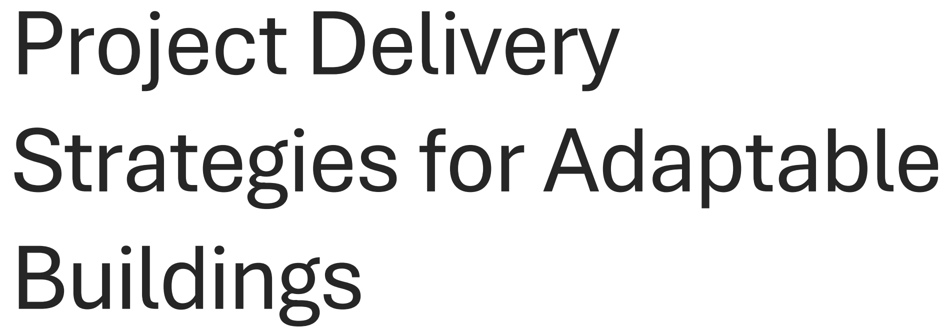

Project Delivery Strategies for Adaptable Buildings

A comparative case study of two Dutch modular projects

Fransiskus Xaverius Prisyafada
CONSTRUCTION MANAGEMENT AND ENGINEERING

Project Delivery Strategies for Adaptable Buildings

A comparative case study of two Dutch modular projects

By

Fransiskus Xaverius Prisyafada

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Student number: 5051304
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Thesis committee:
Chair & First Supervisor: **Dr. Ad Straub**
Faculty of Architecture and the Built Environment
Department Management in the Built Environment (MBE)

Second Supervisor: **Dr. Johan Ninan**
Faculty of Civil Engineering and Geosciences
Department of Materials, Mechanics, Management and Design (3Md)

Preface

The journey to this Master's thesis has been one of both academic discovery and personal reflection. Having spent several years in the Indonesian construction industry, I have witnessed firsthand the pressure to deliver projects quickly and cost-effectively. While we celebrated the completion of new buildings, I often wondered about their future. What would happen in ten, twenty, or fifty years when needs changed? The conventional "build, use, and demolish" model seemed increasingly unsustainable in a world facing climate change and rapid urbanization. This question, how we can build for the long term, became the driving force behind my decision to pursue a Master's degree in Construction Management and Engineering at TU Delft.

This thesis, "Project Delivery Strategies for Adaptable Buildings," is my attempt to answer that question. It represents a bridge between my practical experience in the field and the theoretical aspects of academia. My research quickly revealed that adaptability is not simply a technical challenge of clever design or modular components. It is fundamentally a project delivery problem, rooted in how we structure our workflows, align our stakeholders, and plan for a building's entire lifecycle. This work is therefore dedicated to managing these complex socio-technical systems, with the hope of providing a clear and actionable framework for an industry in transition. The goal is to help shift our collective focus from short-term completion to long-term value, creating a built environment that is not only efficient today but also resilient and prepared for the challenges of tomorrow.

This journey would not have been possible without the support of many individuals. I would first like to express my deepest gratitude to my supervisors, Dr. Ad Straub and Dr. Johan Ninan. Dr. Straub's profound expertise in project management and his insightful questions consistently pushed me to deepen my analysis and clarify my arguments. Dr. Ninan's guidance on theoretical framing and academic writing was invaluable, helping me to structure my thoughts and elevate the research to a higher level. Their combined mentorship was the perfect blend of practical focus and academic aspect.

I am also profoundly grateful to the Indonesia Endowment Fund for Education (LPDP) for providing the full scholarship that made my studies at TU Delft possible. This opportunity has been life-changing, and I am honored to have been a recipient.

A special thanks must go to the professionals and project teams from the two case studies who generously shared their time, experiences, and data. Their willingness to open their projects to scrutiny provided the rich, real-world insights that form the heart of this thesis.

Finally, I would like to thank my family and friends, both in the Netherlands and back home in Indonesia, for their unwavering encouragement and support. Their belief in me has been a constant source of motivation. This work is as much a product of their support as it is of my efforts.

I hope this thesis serves as a valuable contribution to the ongoing conversation about the future of our built environment.

Fransiskus Xaverius Prisyafada

Delft, August 2025

Executive Summary

In the face of climate pressure and rapid urban change, the construction industry is tasked with creating a more sustainable built environment. A critical pathway to achieving this is through the development of adaptable buildings, which can extend their functional lifespan and reduce waste from demolition. This research focuses specifically on modular buildings that incorporate Design for Disassembly (DfD) principles, as they represent a key technical enabler for achieving this goal. However, there is a significant disconnect between this ambition and current industry practice. Existing Project Delivery Methods (PDMs) often fail to support long-term adaptability, as they prioritize short-term success, such as cost and schedule, over lifecycle performance. This research addresses this critical gap by investigating how project delivery can be fundamentally restructured to ensure adaptability is not just a theoretical possibility but a manageable and deliverable outcome, with a specific focus on modular construction as a key technical enabler. Therefore, it will answer this question,

"How can project delivery be structured to better support building adaptability in modular construction projects?"

To explore this challenge, this research employed a qualitative comparative case study of two distinct Dutch modular building projects: an owner-driven campus office expansion (Project A) and a policy-driven relocatable housing development (Project B). A socio-technical perspective was adopted to analyze the connection between the technical, process, and social systems of each project. This multi-aspect analysis was operationalized through two analytical tools: the Design Structure Matrix (DSM) was used to map and analyze the sequence of project activities and their interdependencies, while the Responsibility Assignment Matrix (RACI) was used to clarify stakeholder roles, coordination patterns, and accountability. By combining these methods, this research was able to conduct a holistic diagnosis of the alignment or misalignment between the projects' technical designs, their process workflows, and their stakeholder governance structures.

The comparative analysis of the two case studies provides an important insight: technical capability alone does not guarantee adaptability. Both projects possessed the modular systems necessary for physical modification, but both fell short of their long-term adaptability goals due to significant socio-technical misalignment. This failure can be understood through the lens of a socio-technical framework like Leavitt's Diamond (Figure 0.1), which posits that a project's success depends on the alignment of four interdependent elements: Technology (the modular systems), Tasks (the project activities), Structure (the delivery process), and People (the stakeholders). The research consistently found that while the Technology was adequate, the projects failed due to a misalignment in the other three areas.

The research identified three primary process-related barriers that caused this misalignment. First, delayed technical coordination between siloed design disciplines led to unresolved conflicts (a failure of Structure and People). Second, a lack of formalized lifecycle documentation resulted in the loss of critical knowledge (a failure of Tasks). Third, an informalized coordination line created ambiguous accountability for long-term outcomes (a failure of People).

In response to these findings, this thesis develops a structured delivery framework designed to create this essential socio-technical alignment. The proposed framework is built upon a foundation of 15 interdependent

delivery activities, mapped across six project phases, which systematically integrate critical but often-neglected tasks such as DfD planning and iterative feedback loops. By using the DSM to optimize the Tasks and Structure (the process), and the RACI matrix to clarify the People's roles, the framework provides a clear roadmap for aligning the entire system to support the Technology. This study offers both practical and theoretical contributions, demonstrating that successful adaptability is not merely a technical feature but an output of a holistically aligned project delivery system.

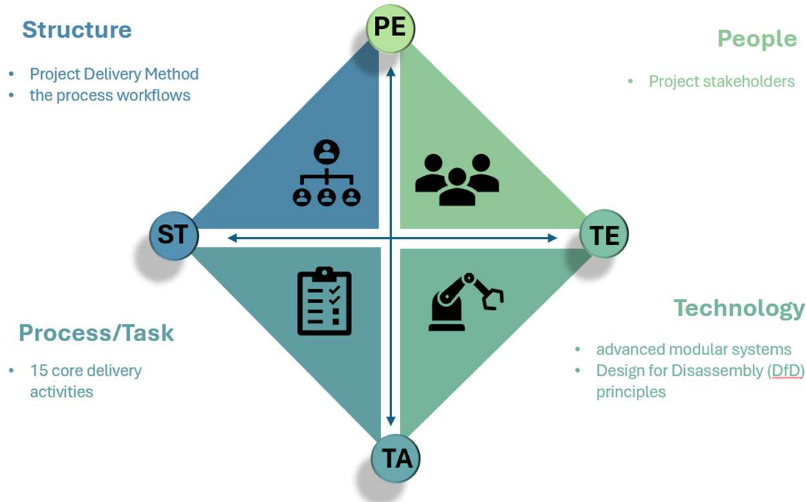


Figure 0.1 Leavitt' Diagram

The research consistently identified three primary process-related barriers that compromised adaptability. First, delayed technical coordination between siloed design disciplines led to unresolved conflicts and on-site rework that constrained future flexibility (Design Integration). Second, a lack of formalized lifecycle documentation, such as DfD plans or material passports, resulted in the loss of critical knowledge required for future reuse (Lifecycle). Third, an informalized coordination line, which allows stakeholders to have different perspectives on the adaptability process (Project coordination). In conclusion, the findings can be divided into enablers and barriers that influence building adaptability, as shown in the Figure 0.2.

	Enablers	Barrier
Design Integration	**Modular Reuse Logic** Use of a standardized modular system to reduce rework	**Lack of Formal DfD Integration** Disassembly and reuse requirements were not embedded as project constraints
	Design Familiarity Design reuse from previous projects reduced lead time	**Late Technical Coordination** specialized contractors joined after key layout decisions, causing routing conflicts and on-site rework.
Lifecycle	**Early Contractor Involvement** The contractor's early input on constructability and modularization streamlined the design process	**Missing Lifecycle Documentation** No structured handover of reuse-related documents
	Presence of Formal Drivers Adaptability was enabled when driven by formal requirements, such as a 15-year municipal permit	**Unclear Accountability for Post-Use Planning** It was unclear who was responsible for the second phase of the projects
Project Coordination	**Informal Coordination Culture** Trust-based relationships allowed for agile decision-making and rapid on-site problem-solving	**No Feedback Capture** Lessons learned from Office Lab 1.0 were applied tacitly but never documented formally for future adaptation.
	On-site Adjustment Capability Lack of planning causes the need for on-site adjustments; the capability to do so will help solve the problems	**Siloed Actor Roles** Structural and MEP engineer were not consulting the design each other during early spatial planning

Figure 0.2 Enablers and Barriers on Implementing Building Adaptability

In response to these findings, this thesis develops a structured delivery framework designed to bridge the gap between adaptability ambition and delivery reality. The proposed framework is built upon a foundation of 15 interdependent delivery activities, mapped across six project phases, which systematically integrate critical but often-neglected tasks such as DfD planning, modular reuse logic, and iterative feedback loops from the project's inception. By using the DSM to optimize activity sequencing and the RACI matrix to clarify stakeholder roles, the framework provides a clear roadmap for aligning the technical, process, and social systems of a project.

This study offers both practical and theoretical contributions. For practitioners, it provides a tangible method to move beyond reactive problem-solving toward a proactive and integrated delivery strategy. For the academic field, it demonstrates that successful adaptability is not merely a technical feature but an output of a holistically aligned project delivery system, offering a vital step toward creating a built environment that is not only constructed efficiently today but is also prepared for the challenges of tomorrow.

Figure 0.4 Practical Implementation for Stakeholders

Contents

Preface ii
Executive Summary iii
List of Figures ix
List of Tables x
Chapter 1: Introduction 11
1.1 Background 11
1.2 Problem Definition 12
1.3 Research Gap 13
1.4 Research Objective 13
1.5 Research Question 13
1.6 Relevance 14
1.7 Scope and Delimitations 14
1.8 Thesis Structure 14
Chapter 2: Literature Review 16
2.1. Building Adaptability 16
2.2. Project Delivery Method (PDMs) 18
2.2.1 Project Delivery Method 18
2.2.2 Key Dimensions of Project Delivery Models 19
2.3. Actor Perspectives on Adaptable Construction 20
2.3.1 Actors/Stakeholders 20
2.3.2 Client-led vs. supplier-led approaches 23
2.3.3 RACI Matrix 25
2.4. Design Structure Matrix (DSM) in Construction 26
2.4.1 Concept of DSM 26
2.4.2 Step Creating DSM 28
2.5 Socio-Technical Frameworks in Project Management 32
2.6 A Synthesized Activity Framework for Adaptable Delivery 32
2.5. Knowledge Gap Summary 35
Chapter 3: Methodology 38

3.1. Research Design ... 38
3.2. Definition of Key Actor Roles ... 39
3.3. Case Selection Criteria ... 40
3.4. Data Collection ... 41
3.5. Data Analysis Process ... 43
Chapter 4: Case Study Findings ... 45
4.1 Case Study A – The Office Expansion Project ... 45
4.1.1 Project Overview ... 45
4.1.2 Delivery Activities & Actor Coordination Analysis ... 46
4.1.3 DSM Analysis ... 49
4.2 Case Study B – The Relocating Housing ... 51
4.2.1 Project Overview ... 51
4.2.2 Project Overview & Actor Coordination Analysis ... 51
4.2.3 DSM Analysis ... 54
Chapter 5: Cross-Case Comparison and Findings ... 56
5.1 Cross-Case Comparison ... 57
5.1.1 Design Integration ... 61
5.1.2 Lifecycle Planning: Ambition vs. Reality ... 62
5.1.3 Project Coordination: Formal vs. Informal Mechanisms ... 64
5.2 Key Findings: Barrier and Enablers to Adaptability ... 65
5.2.1 Enablers and Barriers ... 65
Chapter 6: A Framework for the Development of Adaptable Buildings ... 69
6.1 The Refined Framework ... 69
6.2 Core Strategies for Implementation ... 71
6.3 The Process Flow for Adaptability ... 74
6.4 Conclusion ... 76
Chapter 7: Discussion ... 77
7.1 The Socio-Technical Nature of Adaptability ... 77
7.2 Revisiting the “Vicious Circle of Blame” ... 78
7.3 Modularity: Technical Capability vs. Delivery Gaps ... 79

7.4 Evaluation of Developed Framework 79
7.5 Implications for Project Delivery Practice 80
7.6 Limitations of the Study 83
Chapter 8: Conclusion 84
8.1 Introduction 84
8.2 Answering the Sub-Questions 84
8.2.1 Influential Activities and Decisions (Answering SQ1) 84
8.2.2 Stakeholder Interactions and Roles (Answering SQ2) 85
8.2.3 Similarities and Differences Across Cases (Answering SQ3) 86
8.3 Structuring Project Delivery for Adaptability (Answering the Main Research Question) 86
8.4 Contributions of Research 87
8.5 Recommendations for Future Research 88
References 90

List of Figures

Figure 1 Multiple-case study procedure (Yin & Campbell, 2018) 14
Figure 2 Different aspects of adaptive capacity (Geraedts & van der Voordt, 2014) 18
Figure 3 Fragmentation between industry stakeholders occurs throughout the building life cycle (Pinder et al., 2013) 20
Figure 4 Interplay between influencers and beneficiaries when designing for adaptability (Pinder et al., 2013) 22
Figure 5 The Vicious Circle of Blame (Hartenberger, 2008) 22
Figure 6 Framework of the adaptive capacity method for the demand (for use and transformation dynamics), and the supply (of rearrange, extension and rejection flexibility) (Geraedts & van der Voordt, 2014) 23
Figure 7 Three basic system configurations in DSM: parallel, sequential, and coupled relationships (Yassine, 2004) 27
Figure 8 Relationship between activities 27
Figure 9 Three Configurations that Characterize Activities 28
Figure 10 Step using DSM 28
Figure 11 An example: Original DSM (left) and Partitioned DSM (right) 30
Figure 12 Clustering DSM 31
Figure 13 Leavitt's Diagram Model 32
Figure 14 Research Design Framework 39
Figure 15 Timeline of project lifecycle: Project A (Office Expansion) and Project B (Relocatable Housing) 41
Figure 16 Bottom-up analysis with Gioia 43
Figure 17 Documentation of Project A 45
Figure 18 Organizational Chart of Project A 46
Figure 19 Project B Concept drawings 51
Figure 20 Project B's organizational chart 52
Figure 21 Organizational chart comparison 57
Figure 22 Enablers and Barriers of Implementing Adaptable Building 66
Figure 23 Strategies for Building an Adaptability Project 71
Figure 24 Process Flow of Adaptability Building Project 75
Figure 25 Leavitt's Diamond Diagram 78
Figure 26 Practical implications for stakeholders 81

List of Tables

Table 1 Various Terminologies of Adaptabilities 16
Table 2 Similarities and differences between adaptability, flexibility and DfD (Mlote et al., 2024) 17
Table 3 Stakeholder Perspective on Building Adaptability (Pinder et al., 2013) 21
Table 4 The Difference between Client-Led Approach and Supplier-Led Approach 24
Table 5 list of PDM Activities related to building adaptability 33
Table 6 Correspondence Details 42
Table 7 Activity Analysis of Project A 46
Table 8 DSM Matrix of Project A 49
Table 9 Activity Analysis of Project B 52
Table 10 DSM Matrix of Project B 54
Table 11 Project Delivery Contexts 57
Table 12 DSM Comparison snapshot 58
Table 13 Actor role mapping (selected activities) 59
Table 14 Comparison between Case A and Case B 60
Table 15 Refined DSM Matrix 69
Table 16 Refined RACI Matrix 69

1

Chapter 1: Introduction

This chapter presents an overview of global issues and how building adaptability can contribute to them. Building adaptability is seen as one promising solution to these issues, though the proper project delivery method is still needed to realize it. The research questions are then formulated following the research gap and research objective. This chapter lays the foundation for understanding the significance of the research's background.

1.1 Background

Industry Challenge and Environmental Impacts

According to the United Nations Environment Programme (2025), the building and construction sector accounted for 34% of total global CO_2 emissions, making it the highest-emitting sector globally. Therefore, it is important to find ways to reduce buildings' carbon footprint. Previous research has shown that sustainability can be achieved by the choice of materials and processes, especially renewable materials such as wood and its composites (Mlote & Budig, 2022). However, apart from the selection of materials, the longevity and maintainability of buildings are also essential factors to be considered (Mlote et al., 2024). In addition, urbanization, political instability, climate change, and technological transformation are societal challenges mainly due to the difficulty of predicting (Ross et al., 2016).

The future need for building adaptability

One way to overcome these problems is to ensure that buildings can accommodate the changing demands of society, community resistance, the need for new infrastructure, the pressure of climate change, and functional obsolescence (Ninan et al., 2024), thereby extending their lifespan and reducing the need for demolition and new construction. This will be of great help because cities are growing rapidly, driven by economic, social, and environmental challenges (Manewa et al., 2016), which leads to high demand for a variety of building types and may require frequent reconstruction. Without adaptability, buildings will be left empty, demolished or rebuilt with new structures to accommodate growing demands and changing needs. Furthermore, if this occurs frequently, it will lead to a scarcity of resources and contribute to environmental degradation.

Why the construction industry needs to shift toward adaptable solutions

One of the key principles of sustainability is that development today should not sacrifice the capability of future generations to fulfill their own need (World Commission on Environment and Development, 1987). However, most buildings are traditionally designed as static and permanent structures, which limits their capability to respond to changing demands (Askar et al., 2021). As a result, these outdated structures cause high building vacancy rates (building redundancy), leading to substantial refurbishment or premature demolition that both imply high costs and create large amounts of waste, which is only partially reused or downcycled into lower-quality products (Manewa et al., 2016).

Specifically in the Netherlands, due to the housing shortage on temporarily available land, which is often subject to future zoning changes, national planning authorities have documented that flexible and relocatable housing models (*flexwonen*) are increasingly being deployed to address this issue (Groot, 2022). This trend represents a policy-driven response to address the urban land issue in densely populated areas. They need fast-construction housing, with permanent quality, but have the capability to modify in the future when the permit ends.

These changes often happen in the whole life cycle of a building without being intended when they were initially designed and constructed (Pinder et al., 2013). One of the main problems is that buildings are made in such a way that many changes or alterations can cause the demolition of building parts or even whole structures (Durmisevic & Brouwer, 2022). Therefore, it is important to implement building adaptability to prolong their lifespan and reduce waste and resource consumption, which also aligns with environmental, social, and economic sustainability goals (Gosling et al., 2013).

Building adaptability is the capability of the building to accommodate change over, even in the use phase, without doing major deconstruction, which also supports resource efficiency, sustainability, and long-term value (Geraedts & van der Voordt, 2014). However, delivering an adaptable building is not just a matter of material selection or design, it is also influenced by how construction projects are managed, planned, and delivered.

1.2 Problem Definition

The existing Project Delivery Method (PDM) framework is often siloed from life-cycle and actor involvement programming. In the design, construction, and maintenance phases, it focus solely on the immediate function of a specific part of the project. The project delivery selection does not properly consider that the cycles are interconnected (Ahmed & El-Sayegh, 2020). They also do not consider how unmanaged activity interdependence may hinder future building modifications. Moreover, a lack of early stakeholder involvement will limit the potential of building adaptability to maintain or add its value (Pinder et al., 2013). This gap between adaptability and PDM consideration makes a critical opportunity unaddressed.

Despite growing recognition of its importance, adaptability rarely becomes a priority in early project decisions, especially during the selection of PDM. PDM, such as Design-Bid-Build (DBB), Design-Build (DB), or Integrated Project Delivery (IPD), has a great impact on shaping roles, responsibilities, timelines and

stakeholder relationships during the early design and planning phase (Walker, 2018). These early decisions have long-term implications on project's ability to change.

However, commonly used project management tools, such as PERT, Gantt charts, or the Critical Path Method (CPM), are limited in addressing interdependence and feedback loops (Yassine, 2004). These tools primarily model sequential or parallel activities, but not enough to present the dynamic interaction that affects adaptability. To bridge this gap, this research explores a different approach to analyzing project activity interdependence and delivery strategies.

1.3 Research Gap

While previous research has explored both PDM performance and building adaptability, integration between these domains remains limited. Especially in these points:

- Few studies examine how adaptability considerations can be embedded into the early planning of project delivery.
- Existing PDM selection methods often rely on short-term, project-level success criteria (e.g., cost, time, quality) and neglect broader lifecycle implications, especially how interdependence between activities and actor roles shape long-term flexibility (Ahmed & El-Sayegh, 2020).
- The application of Design Structure Matrix (DSM) in construction remains underutilized for strategic PDM structuring, especially in the context of adaptable buildings (Giancarlo, 2004; Zhong et al., 2022).

Given its ability to model interdependencies and information flow, DSM presents a promising method for analyzing and improving PDM structuring in adaptable construction.

1.4 Research Objective

The objective of this research is to develop a structured framework for enhancing Project Delivery Method (PDM) that supports building adaptability. By utilizing the DSM and RACI matrix to analyze the interdependencies between project activities and coordination among actors, this research aims to identify delivery strategies that enhance the adaptable building's capabilities to accommodate future changes, such as expansion, reconfiguration, or relocation. The framework will be informed by both literature and case-based insights, with a focus on integrating adaptability considerations into the project lifecycle.

1.5 Research Question

Main Research Question

- How can project delivery workflows be structured to better support building adaptability in modular construction projects?

Sub-Questions

1. What delivery activities and decisions influence a building's capacity to support adaptability over time?
2. How do stakeholders interact during the project lifecycle to support adaptability?

3. How do the observed similarities and differences in project delivery structures and coordination processes between the case studies influence their respective capacities to deliver long-term building adaptability?
4. How can project delivery strategies be structured to support building adaptability throughout the project lifecycle better?

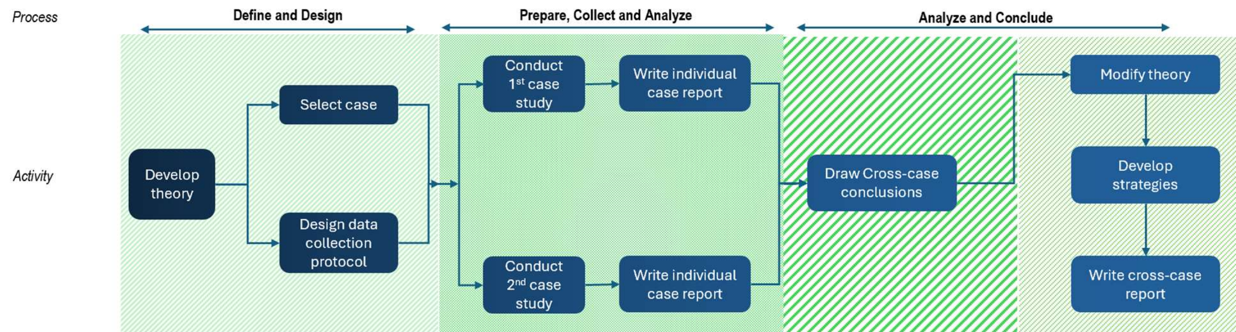


Figure 1 Multiple-case study procedure (Yin & Campbell, 2018)

1.6 Relevance

This research explores the role of PDM in supporting adaptive construction and investigates how different models impact design flexibility. Incorporating the DSM and RACI matrix provides a structured framework for analyzing and enhancing project flow on building adaptable projects.

1.7 Scope and Delimitations

This thesis focuses on construction projects that use adaptability principles at the building level, such as expansion, vertical expansion, or relocation. While the research is not limited to any single construction typology, the case studies primarily come from modular and industrialized building projects, where adaptability becomes one of their main benefits.

To gain a deep understanding of the project's dynamics, interviews will be conducted with various stakeholders, including clients, architects, contractors, manufacturers, and specialized contractors. The geographical focus is limited to projects in the Netherlands.

1.8 Thesis Structure

This thesis is composed of five key chapters. Chapter 1 introduces the research background, problem definition, and research objectives. Followed by chapter 2, which provides a literature review on the key concepts, such as building adaptability, project delivery models, the DSM, and the RACI matrix. Chapter 3 explains the research methodology, specifically the case studies approach, data collection method, and DSM integration in the analytical process. Next is Chapter 4, which presents research findings, including case-specific DSM and RACI analysis. Furthermore, Chapter 5 discusses cross-case comparisons to identify the adaptability project pattern to find potential enablers and barriers for similar projects. Chapter 6 presents practical recommendations that outline an enhanced framework for adaptability projects, including delivery strategies, as well as suggestions for future research. Chapter 7 consists of a discussion of the previous

findings and their relation to the real-world practical. Finally, Chapter 8 provides the answered questions from this thesis, contribution to the research and recommendations for future research.

2

Chapter 2: Literature Review

2.1. Building Adaptability

Being adaptable is defined as the capability of being adapted and suitable to or fit with specific situations (Askar et al., 2021). In system engineering, adaptability can be defined as the ability of a system to change to follow changes in its environment (Haberfellner & De Weck, 2005). A primary objective of adaptability is the ability to prolong the proper lifetime of a building (Addis & Schouten, 2004). Most buildings become abandoned before their technical life comes to an end, because there are inevitable mismatches created between the supply of space and the demand for it (Leaman et al., 1998).

Building adaptability comes in many forms of change, Table 1 shows the various terminologies and their relation to the different types of adaptability by considering the change they imply (Askar et al., 2021).

Table 1 Various Terminologies of Adaptabilities

Change factors	Terminologies	Description	Linkage to Adaptability
Changeable components	**Reusability**	Used again in its original form.	A dimension of adaptability.
	Refitability	Exchanging, replacing, or renovating components.	The ability to replace components increases adaptability options.
Components	**Modularity/Standardization**	The standardization of components sizes and interfaces.	Facilitates reconfiguration of spaces, reuse and replacement of components.
	Changeability	Changeability has four aspects: adaptability, flexibility, robustness, and agility.	Allows products changeability across product platforms.
	Upgradability	Choosing systems and components that anticipate and accommodate increased performance requirements.	Upgradable components allow performance adaptability.
Location	**Movability**	Changing configurations/locations.	A dimension of adaptability.
Performance	**Adaptive reuse**	Defined as the process of extending the useful life of historic, old, obsolete, and derelict buildings.	Reuse of existing structures.
Purpose	**Convertibility**	Determines the ability of buildings to shift between different uses/functions.	Adaptable use of space.
Size	**Scalability/ Expandability/ Extendibility**	Increasing/decreasing the building size.	A dimension of adaptability.

Change factors	Terminologies	Description	Linkage to Adaptability
Space and layout	**Simplicity**	Designing simple structural systems (e.g., repeating layouts and grids, larger but fewer components).	Creates easily understood load paths, reducing uncertainty for adaptable solutions.
	Versatility	Represents the physical change of space (i.e., spatial layout).	Versatility is a branch of flexibility that is a strategy of adaptability.
	Open Plan	Free of structural, mechanical and other obstructions. Components in the space plan layer can be more easily reconfigured.	Open plan layouts grant facilitated adaptation of interior spaces.
	Generality	The ability of a building to meet changing functional purposes without changing its core properties (passive support for change).	A concept/dimension of adaptability.
	Flexibility	The ability of a building to meet changing functional user or owner needs by changing its properties easily.	A concept/dimension of adaptability.
	Elasticity	The ability of a building to be extended, shrunk, or partitioned as required.	A concept/dimension of adaptability.
	Transformability	The ability of a part of a complex adaptive system to assume a new function.	Adaptability manifests in short-term behavior while transformation into a new state refers to a longer period.

The general understanding of adaptability comes from a shift in the conventional perception of buildings as static, finished objects to dynamic systems consisting of objects and processes of construction, change, deconstruction, and reconstruction (Askar et al., 2021). Furthermore, due to the nature of varying terms describing adaptability, summaries of the similarities and differences among the three most recently and commonly used terms to define the adaptability of buildings, that is “Adaptability,” “Flexibility,” and “Design for Disassembly (DfD),” can be seen in Table 2.

Table 2 Similarities and differences between adaptability, flexibility and DfD (Mlote et al., 2024)

Similarities	Differences			
	Factor	**Adaptable buildings**	**Flexible buildings**	**Design for disassembly (DfD)**
1. All address the evolving needs (allow reconfiguration and repurposing to an extent) 2. All seek to minimize waste - Reduce the need for new construction -Environmentally friendly 3. All aim to maximize the potential use of space	Scope	Long-term view	Short-term changes	End-of-life reuse/recycle
	Cost	Requires upfront investment and planning	Upfront cost-effective but may need frequent maintenance	Upfront investment and planning + Higher labor and time
	Scale	Large-scale projects: on the building scale	Small-scale projects: down to room/floor plan scale	Any/Both due to focus: mostly down to component or connections scale (per installation)
	Objective	Meeting major changing occupancy needs by extending the value of the structure in the long run	Easy and quick spatial reconfiguration when required	Reducing waste by reusing building materials and components

A study done by Mlote et al. (2024) provides the benefits of adaptable buildings. This study groups them based on functional, environmental value, economic feasibility, and social equity. Functional benefits include increased flexibility and resilience, as adaptive buildings can accommodate changing uses and conditions. Environmental benefits include reduced resource consumption and carbon emissions, as adaptive building strategies encourage more energy-efficient and waste-efficient practices. Economic benefits include cost savings and increased return on investment, as adaptive buildings can respond to changing user needs and market conditions without requiring large capital investments for early demolition and reconstruction. Finally, social benefits include increased user satisfaction and well-being, as adaptive buildings can provide more diverse and accessible spaces that accommodate a variety of activities and user groups.

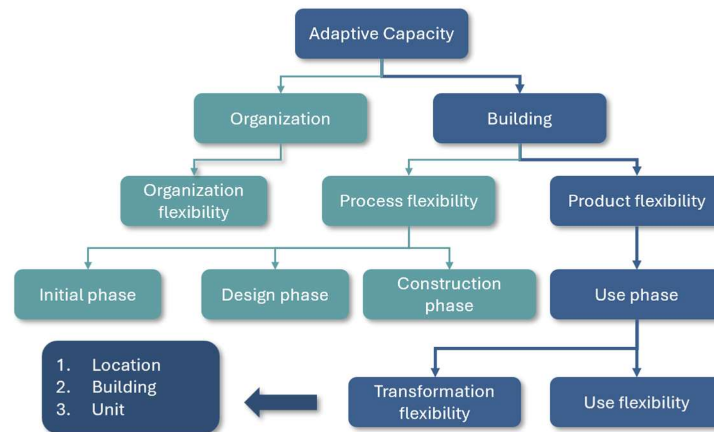


Figure 2 Different aspects of adaptive capacity (Geraedts & van der Voordt, 2014)

Framework by Geraedts & van der Voordt (Geraedts & van der Voordt, 2014) on Figure 2 clarify how adaptability emerges across both organizational and physical parts of a project. On the building side, product flexibility refers to the transformation in the use phase, which accommodates the buildings to change in location or the building itself.

2.2. Project Delivery Method (PDMs)

2.2.1 Project Delivery Method

The Project Delivery Method (PDM) is crucial for everyone involved in project management, regardless of the industry. Moreover, the PDMs discussed in this study apply to the construction industry. A PDM describes the relationship and working methods among project participants in the process of transforming the owner's goal into completed facilities (Chen et al., 2011). It affects construction performance, such as schedule, cost, quality, and efficiency (Al Khalil, 2002). The PDM can be seen as both a contractual structure and a compensation arrangement that the owners use to obtain completed infrastructures that meet their needs (Mafakheri et al., 2007).

As complexity increases, adjustments are necessary to the management structures within projects. Project delivery methods are based on elements such as integration, systemic management, simultaneous

management, team utilization, and the simultaneous and interdependent management of functional plans internally (Williams, 1999).

2.2.2 Key Dimensions of Project Delivery Models

To ensure the PDM functions properly, it is essential to understand the key dimensions of PDM, which can also be mapped to enhance the overall project delivery process.

1. Defining the Fundamental Structure and Relationships (Actor Roles and Responsibilities)

A key concept for differentiating PDMs is the method for assigning responsibility to an organization or individual for providing design and construction services (Ahmed & El-Sayegh, 2020) and contracts are the mechanisms that formalize these roles and responsibilities (Al Khalil, 2002).

Moreover, different PDMs allocate specific tasks and decision-making authority to different actors (owner, designer, contractor, construction manager, etc.) (Engebø et al., 2020). The clarity of these roles is crucial for project success, especially in managing complexity and stakeholder interactions (Forbes & Ahmed, 2010). The definition of roles and responsibilities inherently determines how project risks are distributed among the participants (Touran et al., 2009).

2. Optimizing Project Flow and Timing (Lifecycle Phase Involvement)

Traditional methods like DBB typically follow a linear, sequential process (design fully, then bid, then build) (Alleman et al., 2017). Many alternative PDMs (DB, CM at Risk, IPD) evolved to allow for overlapping phases or "fast-tracking," where construction can begin before design is complete, aiming to shorten overall project duration (Mahdi & Alreshaid, 2005).

Furthermore, a major driver for the development of alternative PDMs was the recognition of benefits from early contractor or construction manager involvement during the design phase (Mafakheri et al., 2007). This early input can improve constructability, cost-effectiveness, and innovation (Touran et al., 2009). The point at which different parties join the project influences how well the adaptable building project can change or evolve the scope definition (Alleman et al., 2017).

3. Enhancing Collaboration and Mitigating Fragmentation (Design Integration)

The relationship between the design process and the construction process is a critical determinant of project success, influencing quality, cost, and potential for disputes. Traditional DBB methods are characterized by a distinct separation between design and construction entities and responsibilities, which was often identified as a source of inefficiency and miscommunication (Walker, 2018). Alternative PDMs like DB and IPD emerged to foster greater integration and collaboration between design and construction disciplines (Engebø et al., 2020). Integrated teams can better address complex technical challenges and explore innovative solutions through shared knowledge and collaborative problem-solving (Ahmed & El-Sayegh, 2020). Tools like Building Information Modeling (BIM) often support these integrated processes as a communication tool (Walker, 2018).

Design Integration focuses on *how* the design and construction efforts are coordinated and unified. This element is crucial for overcoming the traditional fragmentation of the construction industry, improving collaboration, enhancing buildability, and fostering innovation (Davies et al., 2019).

In summary, these three elements, Actor Roles and Responsibilities, Lifecycle Phase Involvement, and Design Integration, are fundamental because they collectively define the operational and relational framework of a project. They determine:

- Who is responsible for what (Actors/Roles).
- When they are involved and when key activities occur (Lifecycle).
- How their efforts, particularly design and construction, are coordinated and unified (Integration).

2.3. Actor Perspectives on Adaptable Construction

2.3.1 Actors/Stakeholders

The success of delivering adaptable buildings depends not only on technical design and construction strategies but also on the involvement of project stakeholders. These actors include the client (owner/developer), architects, contractors, suppliers, facility management, developers, regulators, and tenants. Each actor brings different objectives, risks, and capacities that influence the implementation of adaptable building.

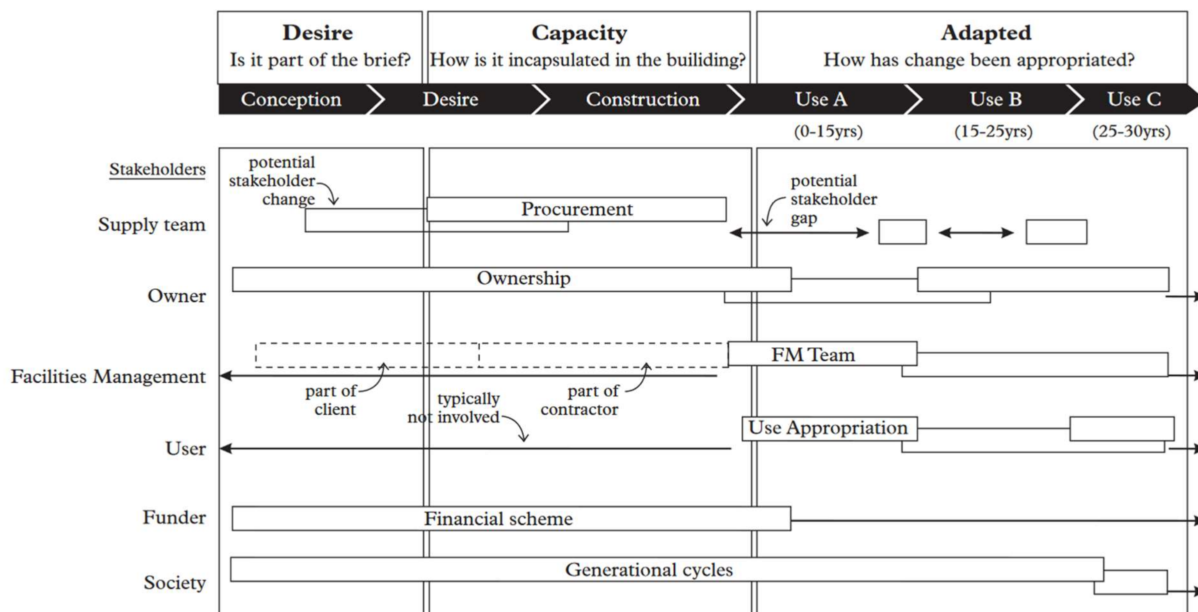


Figure 3 Fragmentation between industry stakeholders occurs throughout the building life cycle (Pinder et al., 2013)

Pinder et al. (Pinder et al., 2013) Provide a helpful framework, as can be seen on Figure 3 to describe the stakeholder positions based on their level of influence and benefit from adaptability. This framework can explain the phase that every stakeholder needs to focus on. The use phase becomes one of the critical points, as there will be a gap in this phase since no architect or contractor is involved.

Understanding the dynamics of building adaptability requires not only the technical or managerial side but also the perception of each stakeholder. Each stakeholder has unique properties, concerns, and decision-

making power that shape adaptability implementation. It is important to recognize these perspectives for identifying drivers and barriers to delivering adaptable buildings. The Table 3 shows summaries key stakeholders perspectives on adaptability, roles, motivation and influences in intersect with broader goal of achieving long-term flexibility in the built environment.

Table 3 Stakeholder Perspective on Building Adaptability (Pinder et al., 2013)

Stakeholder Group	Role / Influence in Adaptability	Motivation / Perspective on Adaptability	Key Barriers / Challenges
Clients / Building Owners	Project initiators and decision makers	Focus on the future benefit of adaptability, especially regarding return on investment. Owning and managing the building	This ambiguity, or lack of shared understanding of building adaptability. Adaptability building tends to have a higher initial cost, but uncertain future benefits, so it is not attractive to those seeking short-term profits
Architects / Designers	Design leaders for adaptable buildings	Trying to avoid the risk of 'failed communities' Adaptability is often a function of 'good architectural planning' and future-proof design	The more flexibility created, the more cost there is developing more adaptable buildings was merely an example of 'speculation', therefore, it was sometimes rejected by the client
Contractors / Builders	Construct the building and have to make sure it is buildable	If the contractor is involved in the early stages, they can reduce the reliance on cost. It is easier to work on adaptable building design rather than retrofitting traditional building design.	For non-specialty contractors, adaptability might complicate construction methods and can increase cost/time.
Suppliers / Manufacturers	Provide adaptable products or modular systems	Can promote adaptable solutions through innovative products and prefabrication.	May lack incentives if clients do not specify adaptability needs. Standardization pressure.
Facility Managers / Building Operators	Operate the building with long-term perspectives	Recognize the benefits of adaptability for maintenance and operational flexibility.	Often not involved in early design or delivery stages, so limited influence.
Property Developers	Project financiers	Typically prioritize building that's marketable as possible, and appeal to the broad market over adaptability, unless the client demands it	Some developers have short-term business models, based around the sale of their newly completed buildings, and therefore focus on minimizing construction costs The maximum possible flexibility probably equates to the maximum cost of build and design.
Tenants / End-users	Occupants, limited design-stage influence	Benefit from flexibility in space use over time.	Rarely involved in early decision-making, passive role.

Research done by Pinder et al., (Pinder et al., 2013) on Figure 4 stated that developing more adaptable buildings can provide a range of potential benefits. However, often the beneficiaries (society, end-users, future owners, facilities managers) have very limited influence on how the buildings are designed and constructed to ensure these benefits are realized.

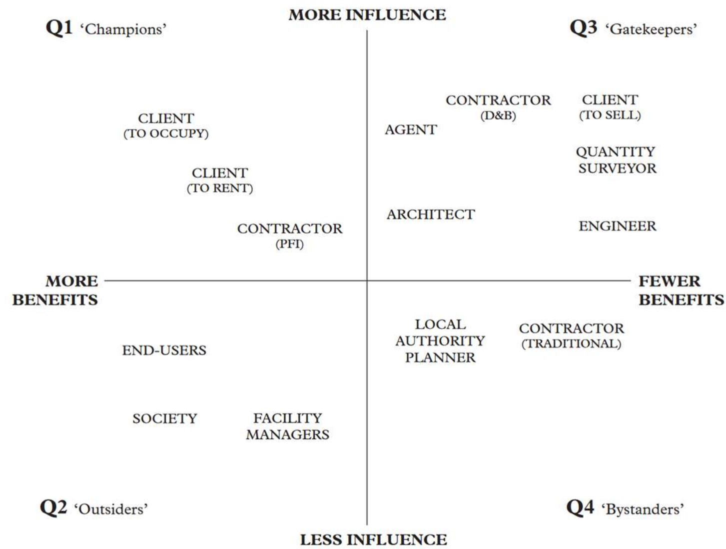


Figure 4 Interplay between influencers and beneficiaries when designing for adaptability (Pinder et al., 2013)

A shift in the stakeholder mindset is necessary to make adaptable buildings more widely accepted in the market. Different perspectives of stakeholders contain different agendas that support adaptability in their own way but also have their own barriers. This complex relationship led to the slow adoption of adaptable buildings. The same goes for the slow adoption of sustainable construction, done by Hartenberger (Hartenberger, 2008), which indicates there is a 'circle of blame' whereby constructors do not produce sustainable buildings because they assume that clients do not want them, who in turn claim that investors will not fund them because there is no demand from owners or end users, as can be seen in Figure 5.

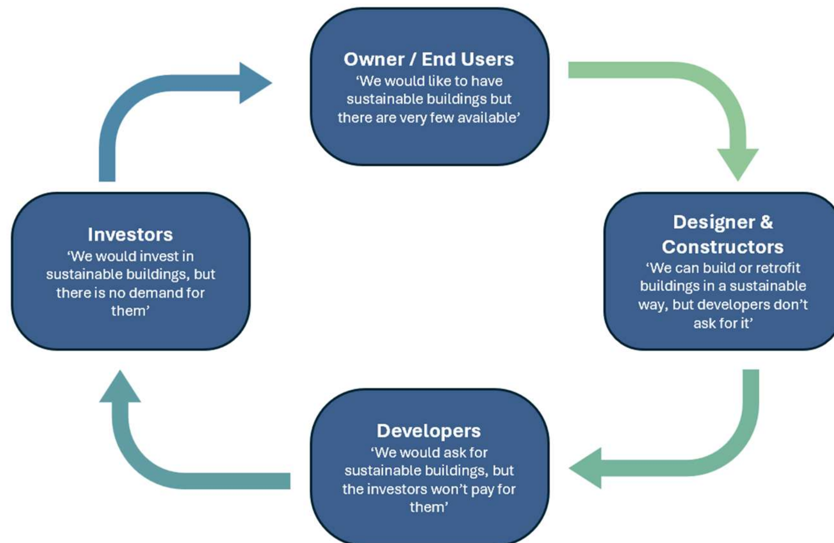


Figure 5 The Vicious Circle of Blame (Hartenberger, 2008)

2.3.2 Client-led vs. supplier-led approaches

Among the various stakeholders involved in adaptable buildings, two play a particularly central role in initiating such projects: the client and the supplier. These roles correspond to two distinct approaches, client-led and supplier-led, each of which shapes how adaptability is embedded in the project. Client-led approaches often use adaptability to secure the future demand of the asset by seeking flexibility, functional changes, or sustainability compliance (Pinder et al., 2013). In contrast, suppliers focus on the benefits of industrialized construction, which includes more standardization and off-site construction, and provide adaptable solutions when there is market demand or client requirements (Gosling et al., 2013). While client-led approaches require early-stage involvement from all relevant stakeholders to realize building adaptability, supplier-led approaches enable adaptability by emphasizing the modularity and prefabrication within the manufacturing process.

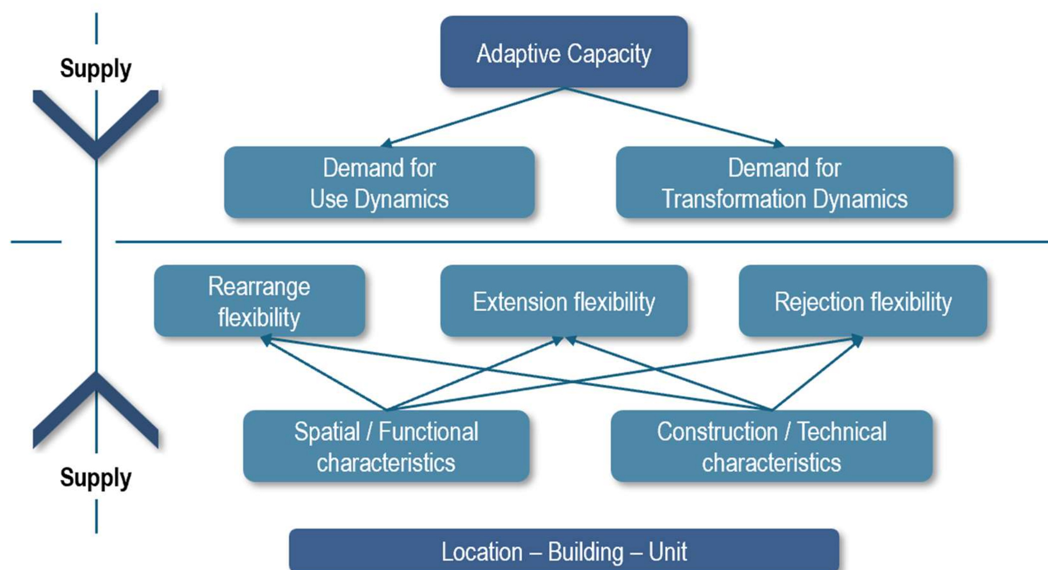


Figure 6 Framework of the adaptive capacity method for the demand (for use and transformation dynamics), and the supply (of rearrange, extension and rejection flexibility) (Geraedts & van der Voordt, 2014)

Demand and supply of adaptability according to Geraedts & van der Voordt (Geraedts & van der Voordt, 2014) on Figure 6 show that there are two different approaches that generate the need for building adaptability. From the perspectives of both the demand (user) and supply (supplier/contractor). Both of them have their reason, and in the end, it is about how the adaptable building can help them to increase value.

Demand for adaptability: use dynamics and transformation dynamics

Changing client needs and user requirements act as key drivers for incorporating flexibility in the building design. This demand arises before the design phase and influences the direction of project requirements. The goal is to transform the user's needs into adaptable buildings across three levels: location, building, and individual units.

To accommodate these changing user needs, the building should be able to support various types of modifications. For instance, a building that can expand, shorten, or even relocate, without demolishing the

whole structure. This is referred to as using dynamics, which emphasize adaptability from the user's perspective.

The supply: rearrange, extension and rejection flexibility

On the supply side, adaptability can be expressed in terms of the building's technical and spatial capacity to meet changing requirements. This involves three types of flexibility:

- Rearrangement Flexibility: The extent to which the location, building, or unit can be reorganized or redesigned.
- Extension Flexibility: The extent to which the location, building, or unit can be expanded.
- Rejection Flexibility: The extent to which parts of the building, unit, or site can be removed or replaced.

These flexibility types define whether a building can adequately respond to changing demands throughout its lifecycle.

The difference between poles can be compared in a detailed way based on several aspects, such as motivation, design influence, cost consideration, risk perception, adaptability integration, and challenge. Table 4 describes the differences between client-led and supplier-led approaches from previous research, which will be used as a base to analyze stakeholders' perspectives in the case studies.

Table 4 The Difference between Client-Led Approach and Supplier-Led Approach

Aspect	Client-led Approach	Supplier-led Approach	Source / Reference
Who drives the project goals?	Client initiates adaptability requirements based on business goals, long-term usability, or sustainability points.	Suppliers promote adaptability as a feature of their product or service offering, often tied to modular or standardized solutions.	Pinder et al. (2013)
Main motivation	Focus on the future benefit of adaptability, especially regarding return on investment. Flexibility on future modifications Keeping long-term asset value	Prefabrication and standardization of systems: suppliers in this type of construction have bargaining power to offer adaptable buildings to the market Long-term collaboration model: the specific connection of the modular building is unique. Therefore, the future modification will potentially be handled by the same supplier	(Mlote et al., 2024), (Pinder et al., 2013),
Design influence	High: Client has their objectives regarding the adaptability, for example, to meet their future benefit	Medium: Suppliers influence design by limiting the unique design of the Designer by modularity, standardization and Prefabrication	Pinder et al. (2013), (Askar et al., 2021)
Cost consideration	Have to ensure the future benefit over the upfront cost investment	There is cost efficiency already from the modularization and standardization Repeat order from building modification will become additional income Custom design for standardization may generate a more expensive cost	(Lu et al., 2021),

Aspect	Client-led Approach	Supplier-led Approach	Source / Reference
Risk perception	Concern about the future-proofing of adaptable building, return on investment, and market uncertainty	Concern about production risk, delivery timelines, and customization complexity.	(Mlote et al., 2024)
Adaptability integration	Have to ensure the integration of adaptability from early stages, coordinate the designer and executor (Contractor, Supplier)	Design and production process: The Manufacturer has the responsibility to	Stakeholder perspectives (Pinder et al., 2013)
Challenges	• Lack of awareness of adaptability benefits. • Budget constraints. • Market uncertainties.	• Standardization pressures. • Balancing customization with production efficiency. • Limited client demand for adaptability and the assumption that adaptability always costs more	All sources

This dynamic raises questions about whose initiative drives adaptability and how it is embedded in the PDM. Projects where adaptability is not intentionally considered early risk, as decisions during delivery may limit future modifications. To secure adaptability, coordination between stakeholders must be structured and aligned through a suitable PDM. This includes defining roles, responsibilities, and feedback mechanisms that support lifecycle thinking, modularity, and change-readiness.

2.3.3 RACI Matrix

A clear framework to map stakeholders' roles and responsibilities is essential for effectively managing the complex interactions between them. A key tool for this purpose is the responsible assignment matrix, most commonly known as the RACI matrix. The RACI matrix is a straightforward yet powerful tool used in project management to define and communicate the roles and responsibilities of various stakeholders for any given task or activity within a project (Project Management Institute, 2017).

RACI is an acronym that defines four key levels of involvement:

- **Responsible (R):** The person or people who do the work to complete the task. They are the "doers" who are responsible for taking action and implementing it. There can be multiple 'R's for a single task.
- **Accountable (A):** The individual who is ultimately answerable for the correct and thorough completion of the task. This person holds the authority to say "yes" or "no" and has the power to veto. It is a critical best practice that for any given task, there is only one Accountable person to avoid confusion over ownership.
- **Consulted (C):** Stakeholders who are sought out for their input and expertise. This typically involves two-way communication, where their opinions and advice are considered before a decision or action is taken.

- **Informed (I):** Individuals who are kept up-to-date on progress or decisions, but do not provide direct input. This is a one-way flow of communication to ensure these stakeholders are aware of project developments.

The main benefit of the RACI matrix is its ability to eliminate role confusion and prevent tasks from being overlooked, as well as streamline the communication and decision-making process. By mapping out who does what, it ensures that all project participants understand their specific responsibilities and the responsibilities of others, which reduces conflict and improves efficiency (Suhanda & Pratami, 2021).

In the context of delivering adaptable buildings, especially where early and continuous collaboration between stakeholders is critical, the RACI matrix serves as a powerful complementary tool to the DSM. While the DSM identifies the technical dependency and information flow between project activities, the RACI matrix clarifies who is responsible for executing those activities and managing the information exchanges.

For example, the DSM might reveal a feedback loop between 'Architectural Design' and 'Structural Engineering.' A corresponding RACI matrix would specify who is responsible for updating the drawings, who is accountable for the final integrated design, and which specialists must be consulted before changes are approved. This combination provides a more holistic view of the project's socio-technical system, mapping not just the 'what' and 'when' of project interdependence, but also the 'who.'

2.4. Design Structure Matrix (DSM) in Construction

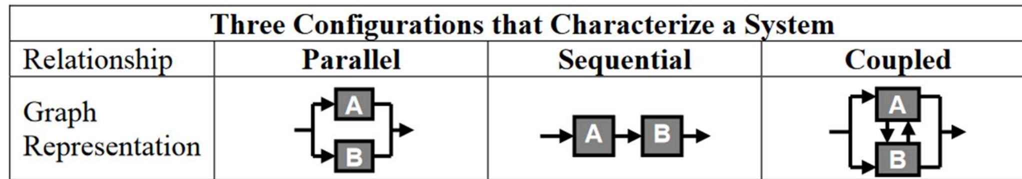
2.4.1 Concept of DSM

Determining a project delivery method that aligns with the characteristics of a construction project is a crucial step that significantly impacts the success or failure of the project. However, the traditional selection method does not originate from the project's internal process, which may result in the delivery method being unable to meet the actual project requirements. A method named the Design Structure Matrix (DSM) is a network modeling tool that reflects the interaction of the system's elements, thereby highlighting the system's architecture (or designed structure) (Eppinger, 2012). The DSM approach allows the project or engineering manager to represent meaningful task or activity relationships to determine a reasonable sequence for the modeled activities (Yassine, 2003). DSM has been identified as a potential tool for simulating interdependent activities, identifying suitable assumptions, and formulating and evaluating results (Maheswari, 2005).

A DSM is defined as a matrix representation of a project network. A DSM provides an idea about various activities of any process that are connected, what information is needed to start an activity, what activity will be followed by any previous activity, and does task sequencing and iterations (Yassine, 2004). Moreover, Khan (Khan, 2016) explains that "DSM is a representation and analysis tool for the system modelling. A DSM displays the relationships between components of a system in a compact, visual, and analytically advantageous format.

According to Yassine (Yassine, 2004), system elements (project activities or phases) can be represented using directed graphs to visualize dependencies. The node on the graph represents a system element, and the edge joining two nodes represents the relationship between two system elements. An arrow visualizes

the directionality of influence from one element to another. These relationships are classified into three basic configurations: **p**arallel, sequential, and coupled (see Figure 7).



Three Configurations that Characterize a System			
Relationship	**Parallel**	**Sequential**	**Coupled**
Graph Representation	A B	A B	A B

Figure 7 Three basic system configurations in DSM: parallel, sequential, and coupled relationships (Yassine, 2004)

The matrix is visualized by a digraph of a binary (filled by number zero or one) square (matrix with the same number of rows and columns) matrix with m rows and columns and n non-zero elements, where m is the number of nodes and n is the number of edges (active links between activities).

The matrix layout can be drawn as follows: the activity names are placed down the side of the matrix as row headings and on the top as column headings in the same order. If there is any active link from node i to node j, then the value of the element ij is unity (marked by X). Otherwise, the value of the elements is zero or left empty. In the binary matrix, the diagonal of the matrix does not have any interpretation, so it will be blacked out.

Mark in a single row emphasizes all activities whose output is needed to run the activity that corresponds to that row. Similarly, reading down a column shows which activities accept the output of the corresponding column. If the order of the activities is in a time sequence, then the mark below the diagonal represents the forward flow of information, which is normal flow, however, the mark above the diagonal depicts information feedback to earlier activities, which indicates an undesirable event, as it creates rework or loops. This is pictured in Figure 8.

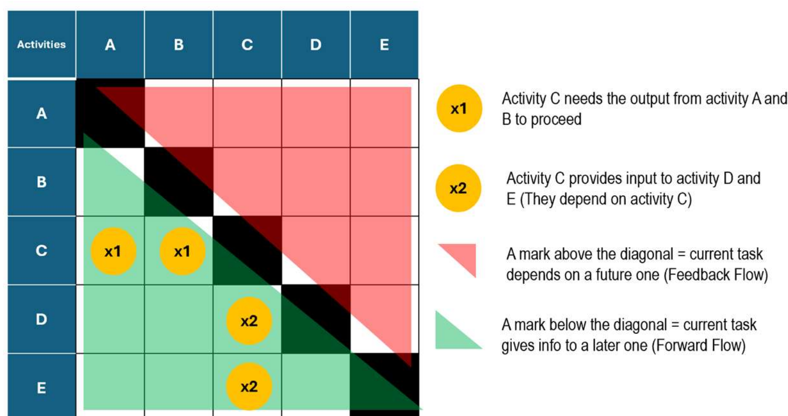


Figure 8 Relationship between activities

Marks in the matrix explain if there is a relation between the activities, and if so, which kind of relation do they have, for example, sequential, parallel, or coupled, as can be seen in the Figure 9.

Three Configurations that Characterize a System									
Relationship	**Parallel**			**Sequential**			**Coupled**		
DSM Representation		A	B		A	B		A	B
	A			A			A		X
	B			B	X		B	X	

Figure 9 Three Configurations that Characterize Activities

In a parallel configuration, the activities do not have any connection with each other. Understanding the behavior of the individual activity allows us to understand the behavior of the system completely. From the parallel relation from Figure 9, it can be seen that activity B is independent of activity A and no information exchange is required between the two activities.

In the sequential configuration, one activity influences the behavior of another activity in a one-directional flow. In the above example, activity A has to be performed first before activity B can start. Furthermore, in the coupled configuration, the flow of influence is intertwined. Activity A influences activity B, and activity B influences activity A. This would occur if parameter A could not be decided clearly without first knowing parameter B, and B could not be determined without knowing A. This cyclic dependency is called "Circuits" or "Information Cycles".

2.4.2 Step Creating DSM

Yassine (Yassine, 2004) has defined the steps that can be adopted for creating a DSM. The steps on Figure 10 are divided into two stages: creating the matrix and redesigning the project. The first stage mainly focuses on building the matrix by gathering the activity list from projects. The next step is to rearrange the activities to enhance the workflow.

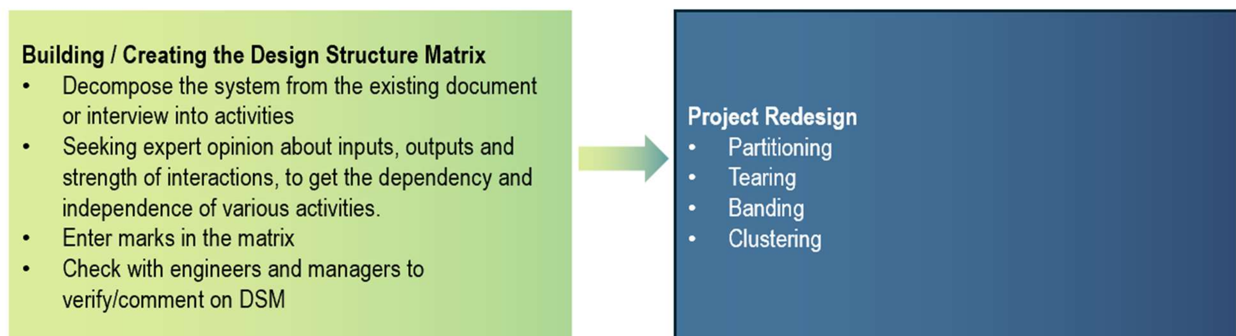


Figure 10 Step using DSM

Stage 1 – Creating the Design Structure Matrix

First, it is necessary to decompose the system into components or activities to create a matrix for DSM. Therefore, it is important to understand the system elements (subsystems or modules). An appropriate decomposition can be established using two main approaches:

1. Convert existing documentation, such as project schedule, design coordination documents, contracts or scope, workflow diagram, quality documents, etc.
2. Structured interview expert, such as project coordinator, client, project manager, contractor, designer, supplier/manufacturer, etc.

The research recommends a hybrid approach: a starting DSM is built from existing documentation, and then expert interviews are used to add to and validate the initial DSM. The decomposition can be hierarchical or non-hierarchical (sometimes called network decomposition). In the hierarchical decomposition, the system can be divided into sub-systems that turn into finer components. In the network decomposition, a system hierarchy is not evident.

Once the appropriate system elements or set of activities have been identified, they are listed in the DSM as row and column labels in the same order. The elements in the form of activities within the matrix are then identified by asking the appropriate stakeholders in the selected projects. In a task-based DSM, this can be the minimum set of activities that need to be performed before the activity under questioning can be started. These activities are marked in the DSM by an 'X' or "●".

Stage 2 – Project Redesign

1. Partitioning - (Reordering) such that feedback marks are eliminated/reduced/closer to the diagonal.

   Partitioning is the process of reordering the DSM rows and columns so that the new DSM arrangement does not contain any feedback marks that transform the DSM into a lower triangular form. For the complex flow of work structure, it is highly unlikely that this reordering will result in a lower triangular form. Therefore, the analyst's objective changes from eliminating the feedback marks to moving them as close as possible to the diagonal. By doing so, fewer activities will be involved in the iteration cycle, resulting in faster project completion.

   Several approaches are used in DSM partitioning. However, they are all similar with a difference in how they identify cycles (loops or circuits) of activity. All partitioning algorithms proceed as follows:

   1. Identify system elements (activities) that can be determined (or executed) without input from the rest of the elements in the matrix. Those elements can easily be identified by observing an empty row in the DSM. Place those elements at the top of the DSM. Once an element is rearranged, it is excluded from further partitioning steps (with all its corresponding marks) and step 1 is repeated on the remaining elements.
   2. Identify system elements (activities) that deliver no information to other elements in the matrix. Observing an empty column in the DSM can easily identify those elements. Place those elements at the bottom of the DSM. Once an activity is rearranged, it is excluded from further partitioning steps (with all its corresponding marks) and step 2 is repeated on the remaining elements.
   3. If, after steps 1 and 2, there are no remaining elements in the DSM, then the matrix is completely partitioned, otherwise, the remaining elements contain information circuits (at least one).

4. Determine the circuits by one of the following methods:
   - Path searching information flows traced either backwards or forwards until a task is encountered twice (Sargent & Westerberg, 1964; Steward, 1981). All tasks between the first and second occurrence of the task constitute a loop of information flow.
   - Powers of the Adjacency Matrix Method: Raising the DSM to the n-th power shows which element can be reached from itself in n steps by observing a non-zero entry for that task along the diagonal of the matrix (Warfield, 1973).
5. Collapse the elements in a single circuit into one representative element and go to step 1.

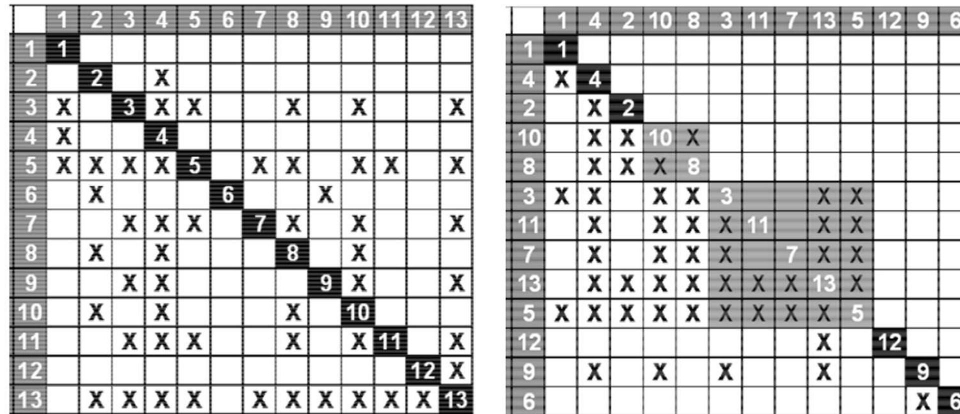


Figure 11 An example: Original DSM (left) and Partitioned DSM (right)

2. Tearing: Choose feedback marks that, if removed from the matrix, will render the matrix lower triangular.
   Tearing is the process of choosing the set of feedback marks that if removed from the matrix (and then the matrix is re-partitioned) will render the matrix lower triangular. The marks that we remove from the matrix are called "tears".
   Identifying those "tears" that result in a lower triangular matrix means that we have identified the set of assumptions that need to be made in order to start design process iterations when coupled tasks are encountered in the process.
   No optimal method exists for tearing, but it is recommended to use two criteria when making tearing decisions:
   - Minimal number of tears: Break only the minimum number of feedback loops necessary to get a workable flow
   - Confine tears to the smallest blocks along the diagonal: these inner iterations are done more often. Therefore, it is desirable to confine the inner iterations to small tasks.

3. DSM Banding: Addition of light and dark bands to show independent (parallel or concurrent) activities.
   Banding is the addition of alternating light and dark bands to a DSM to show independent (i.e., parallel or concurrent) activities (or system elements) (Grose, 1994). The collection of bands or levels

within a DSM is the critical path of the project. Furthermore, one activity within each band is the critical/bottleneck activity. Thus, fewer bands are preferred since they improve the concurrency of the project. In the banding procedure, feedback marks are not considered. This means that they are ignored when determining the bands.

4. Clustering: Forms subsets that are mutually exclusive. These are team formations or independent modules.
   Partitioning is the process of grouping DSM elements (tasks, teams, modules) into mutually exclusive or self-contained groups (modules or teams). In other words, clusters contain most, if not all, of the interactions (i.e., DSM marks) internally and the interactions or links between separate clusters is eliminated or minimized (Fernandez, 1998; Sharman and Yassine, 2003; Yu et al., 2003). In which case, the blocks become analogous to team formations or independent modules of a system (i.e., product architecture). Furthermore, in this setting, marks below the diagonal are synonymous with marks above the diagonal, and they represent interactions between the teams or interfaces between the modules. As an example, in Figure 12, The entries in the matrix represent the frequency and/or intensity of communication (how frequently teams need to work with other teams: daily, weekly, or monthly) exchanged between the different development participants, represented by person A, person B.

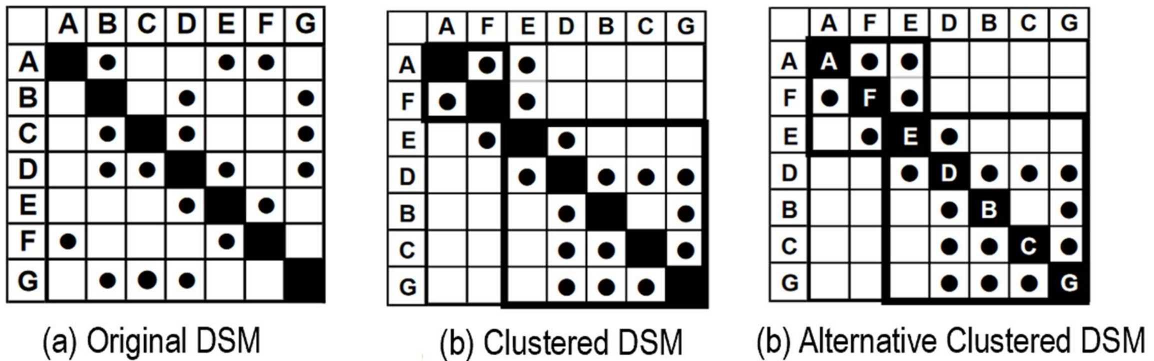


Figure 12 Clustering DSM

This research aims to develop a framework for selecting PDMs that support building adaptability. According to the activity relationship in the DSM, understanding the current delivery method is insufficient, as it is also necessary to design a delivery method more tailored to project requirements based on the activity relationship. The framework uses the DSM method to analyze the interdependence between project activities that support adaptability, such as knowledge transfer, future reconfigurability, and lifecycle performance, which are integrated into the delivery process. By optimizing these interdependencies through combining, sequencing, and prioritizing, the framework helps identify the most appropriate PDMs that align with flexibility and long-term adaptability goals (Lee et al., 2021; Project Management Institute, 2017).

2.5 Socio-Technical Frameworks in Project Management

To understand the persistent misalignment between technical capability and delivery execution in complex projects, it is useful to adopt a socio-technical perspective. Leavitt's Diamond is a seminal socio-technical framework that provides a lens for this analysis (Leavitt, 1965). The model posits that any organization or project is a system of four interdependent variables: Technology, Tasks, Structure, and People (Actors). Leavitt's central argument is that a change in one variable necessitates adjustments in the others to maintain alignment, as can be seen in Figure 13. This concept of systemic alignment is critical for understanding the organizational challenges in delivering adaptable buildings

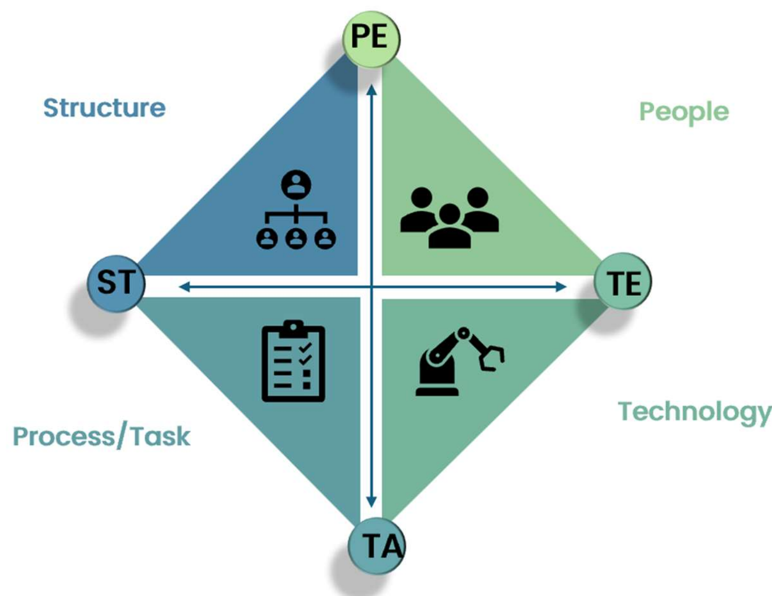


Figure 13 Leavitt's Diagram Model

2.6 A Synthesized Activity Framework for Adaptable Delivery

To analyze and compare how different PDMs support adaptability, a standardized list of project activities is required. This list functions as a foundation for the DSM and RACI analyses in this research. Traditional construction project management neglects activities that are critical for long-term adaptation, such as DfD, post-occupancy planning, and life-cycle documentation. Therefore, a specific activity was developed to ensure these critical elements are explicitly included in the analysis.

The 15 core activities used in this study, as can be seen in Table 5, were synthesized from a comprehensive review of academic literature on project delivery, modular construction, and building adaptability. Key sources include frameworks from PDM selection (Zhong et al., 2022), DfD principles (Ostapska et al., 2024), and constructability management (Khan, 2016). The activities were then clustered into key project phase (Planning, Design, Procurement, etc.) to provide a structured and comprehensive view of the project lifecycle.

The validity of this activity list was established through two processes. First, content validity was ensured by grounding the list in multiple academic sources, as detailed in Table 5. Second, application-based validation

was confirmed during the case study analysis, where the list proved to be an effective instrument for mapping the real-world project delivery workflow and identifying key patterns related to adaptability. Therefore, the list provides a strong and validated foundation for the analysis that follows in this thesis.

Table 5 list of PDM Activities related to building adaptability

Activity Phase	Activity Clustered	No	Activity	Actors	Referenced In
Planning	Establish project intent and adaptability goals	1a	Client needs identification	Client	MDPI Framework (2022)
		1b	Feasibility studies	Contractor, Architect, Specialist Sub-contractor	MDPI Framework (2022)
		1c	Discussion on recycling goals	Contractor, Architect, Specialist Sub-contractor	Khan (2016)
		1d	Review and implementation of past lessons learned	Client, Architect, Facility Manager	Khan (2016)
	Select delivery method and define responsibilities	2a	Composing project delivery strategy	Client	PDM Evolution (2021)
		2b	Define client-contractor-architect roles	Client	PDM Evolution (2021)
		2c	Selecting architect and contractor	Client, Architect, Facility Manager	Khan (2016)
	Appoint key design and execution stakeholders	3a	Conducting surveys	Client, Architect	Khan (2016)
		3b	Working out Construction Schedule	Client, Architect, Facility Manager	Khan (2016)
		3c	Laying out site efficiently	Contractor, Architect, Specialist Sub-contractor	Khan (2016)
Design	Design for disassembly and lifecycle reuse (DfD)	4a	Design planning & lifecycle integration	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
		4b	Disassembly-oriented detailing	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
		4c	Modular detailing & system rationalization	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
		4d	Material strategy & circularity	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
	Develop spatial-modular design	5a	Foundational site & design requirement analysis	Contractor, Architect, Specialist Sub-contractor	Khan (2016)
		5b	Design development & technical detailing	Contractor, Architect, Specialist Sub-contractor	Khan (2016)

Activity Phase	Activity Clustered	No	Activity	Actors	Referenced In
		5c	Circularity, materials, and long-term use planning	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
	Structural Design for Adaptability	6a	Design structural parts (column, beam, foundation, etc)	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
		6b	design lightweight structure	Contractor, Architect, Specialist Sub-contractor	Ostapska et al. (2024)
		6c	over-dimension elements	Client, Facility Manager	Ostapska et al. (2024)
	Design building services (MEP)	7a	Design building services (MEP)	MEP Engineer, Contractor	Khan (2016)
	Coordinate technical layout and system	8a	Review of design by other team members	Client, Architect, Facility Manager	Khan (2016)
		8b	Clash detection (using BIM)	BIM Coordinator (Contractor), Architect, Specialized Sub-contractor	Khan (2016)
		8c	System routing	Client, Architect, Facility Manager	Khan (2016)
	Conduct constructability review and iteration planning	9a	Design coordination between stakeholders	Contractor, Architect, Specialist Sub-contractor	BIM Workflow Mapping (2015)
		9b	Constructability review (via DSM or BIM)	BIM Coordinator (Contractor), Architect, Specialized Sub-contractor	DSM-Constructability (2016)
		9c	Prepare deconstruction plan	Client, Architect, Facility Manager	Ostapska et al. (2024)
		9d	Prepare a documentation plan for adaptable purposes	Client, Architect, Facility Manager	Ostapska et al. (2024)
Procurement	Procure systems, materials, and subcontractors	10a	Select supplier/vendors	Client, Architect, Facility Manager	PDM Performance Comparison (2019)
		10b	Procure materials or services	Client, Architect, Facility Manager	Giancarlo (2004)
Fabrication	Fabricate modules and prepare off-site logistics	11a	Module fabrication	Contractor, Architect, Specialist Sub-contractor	Giancarlo (2004)
		11b	Off-site material integration	Contractor (Factory), Suppliers	Giancarlo (2004)
		11c	Logistics scheduling	Contractor, Architect, Specialist Sub-contractor	Giancarlo (2004)
Execution	Prepare site and foundations	12a	Pre-execution setup & planning	Client, Architect, Facility Manager	Giancarlo (2004)

Activity Phase	Activity Clustered	No	Activity	Actors	Referenced In
		12b	Site preparation & construction process enablement	Client, Architect, Facility Manager	Giancarlo (2004)
		12c	Monitoring, coordination & site efficiency	Contractor, Architect, Specialist Sub-contractor	Giancarlo (2004)
	Deliver and install modules on site	13a	Core construction execution & sequencing	Contractor, Specialist Sub-contractor	DB vs DBB Analysis (2017)
		13b	Monitoring, safety, and quality management	Contractor, Architect, Specialist Sub-contractor	Khan (2016)
		13c	Innovation, adaptation, and knowledge retention	Contractor, Architect, Specialist Sub-contractor	Khan (2016)
	Test systems and perform commissioning	14	Systems testing and commissioning	Client, Architect, Facility Manager	DSM Planning Projects (2016)
Handover & Post-Occupancy	Handover documentation and plan post-occupancy support	15a	Handover of documentation and occupancy certification	Contractor, Architect, Specialist Sub-contractor	PDM Evolution (2021)
		15b	Facility management setup and operation	Contractor, Architect, Specialist Sub-contractor	PDM Evolution (2021)
		15c	Post-occupancy evaluation	Client, Architect, Facility Manager	BIM Workflow Mapping (2015)

2.5. Knowledge Gap Summary

Selecting the appropriate PDM is a crucial managerial decision that significantly influences the success of construction projects (Ahmed & El-Sayegh, 2020). The PDM defines roles on the procurement route, sequence of project phases, and sets a framework for organization, roles, and responsibilities, stating that the choice of PDM is often made ad hoc, with insight into how the decision will influence the final project risk allocation (Engebø et al., 2020). This argument is strengthened by, for example, Lædre et al., (2006), maintaining that clients continue to select the same method based on habit without considering what suits each project. Although a wide range of PDMs exists, stakeholders often lack structured criteria to match the delivery method to the project's adaptability needs. However, no formalized and structured selection process exists for choosing a suitable PDM (Touran et al., 2009).

To choose the appropriate PDM, researchers have developed many methods based on project performance (Alleman et al., 2017) and mathematical models (Chen et al., 2011). These methods and models rely more on expert subjectivity, which is influenced by the evaluators' preferences, expertise, and abilities, and are not adaptable to constantly changing projects. The complexity of the project makes the choice of delivery method often inconsistent, and the evolution of projects constantly creates new features and requirements, which weakens the effectiveness of the model (Zhong et al., 2022).

Although people start to recognize the importance of building adaptability, the understanding of how PDMs can be systematically aligned to support it remains limited. While some studies have addressed PDM performance in terms of cost, time, and quality, very few have explored the internal structure of project activities and their interdependencies as the basis for selecting PDM for adaptable building. This gap presents an opportunity to develop a more structured, activity-based approach using DSMs to inform PDM selection that better supports long-term adaptability outcomes. The DSM in construction research offers a method for capturing and analyzing these complex interrelationships. This approach is supported by a growing body of literature applying DSM in construction and modular design contexts.

A DSM is widely applied in product development and systems engineering, however, its adoption in the built environment is growing, especially in studies focusing on design coordination, modular construction, and lifecycle integration.

- Khan (Khan, 2016) using DSM to study the advantages of applying DSM to the activities, which are based on the concept of Constructability. The results obtained after the final iterations of DSM, give multidimensional analysis regarding their parallel run, sequencing and networking etc.
- Zhong et al., (Zhong et al., 2022) proposes a DSM-based PDM selection framework model that regroups activities and identifies appropriate PDMs by revealing the dependencies and intensities between activities. The research uses a case to demonstrate the feasibility of the framework.
- Yassine (Yassine, 2004) propose how the basic method works and how we can use the DSM to improve the planning, execution, and management of complex PD projects using different DSM features (i.e., partitioning, tearing, banding, clustering, simulation, and eigenvalue analysis).

These precedent supports using DSM as a method for mapping and analyzing the coordination structure of project delivery processes, particularly in projects where future adaptability is an objective but has not been fully integrated into the whole project lifecycle.

While the RACI matrix is a well-established and valuable tool in project management for clarifying operational roles and responsibilities (Project Management Institute, 2017), a review of the literature reveals several gaps in its application in the delivery of adaptable buildings with long-term lifecycles.

The most significant gap is that a traditional RACI matrix provides a static snapshot of responsibilities for a single, well-defined project phase. It is highly effective for managing the design and construction stages. However, adaptable buildings are, by definition, dynamic and designed for multiple future lifecycles (e.g., expansion, relocation, reconfiguration). The existing literature rarely addresses how to use a RACI framework to manage the longitudinal transfer of accountability across these different lifecycle phases.

The second gap lies in its nature as a purely "social" or organizational tool. A RACI matrix defines who is involved in a task, but it provides no insight into the process dependencies, sequencing, or feedback loops that connect that task to others. On its own, it cannot reveal the rework loops or coordination bottlenecks that were identified in this research using the DSM. While some literature discusses RACI and DSM as separate

tools, there is a lack of research that explores their combined application as an integrated socio-technical framework to simultaneously diagnose and improve both the social and process systems of a project.

3

Chapter 3: Methodology

This research aims to understand how project delivery models can be adapted to enhance the workflow of adaptable buildings. Exploratory research is the most suitable approach to gaining this understanding since this case has not previously been studied in depth, as it can develop initial ideas, identify problems, and provide direction for further research (Swaraj, 2019).

Exploratory research is often qualitative in nature. Qualitative data can extract deeper knowledge than quantitative data. Qualitative data is effective in understanding the decision-making processes, collaboration dynamics, and challenges faced by industry practitioners in real-world projects. By doing research with practitioners and analyzing documented cases, this study seeks to capture the relationships between project delivery models and adaptable building.

This section elaborates on the methodology used in this research, starting with the research design as a framework for this research. Followed by how the data was collected, which focuses on the process and type of projects. Since DSM is one of the tools, it will also be used to analyze the collected data. Lastly, the new framework of enhanced PDM and its activity will be developed by using the output from the previous step.

3.1. Research Design

The research design uses a multiple-case study procedure, which captures insight from different cases or projects. This approach explores in-depth explanations of real-world projects and their challenges, workflows, and delivery models. By analyzing multiple cases, this research studies comparative insights and identifies patterns that can become best practices in project delivery.

To get meaningful insight from the cases, it is necessary to cover the holistic levels, not decompose them into separate variables (Yin, 2018). Instead, cross-case synthesis should resemble what has been called a 'case-base' rather than a 'variable-base' approach (Byrne, 2009; Ragin, 1992). A synthesis of findings across multiple cases to generate recommendations on how project delivery models can be adapted to support adaptable buildings.

To integrate the DSM and RACI matrix into research design, four steps by Askar et al., (2021) are merged with the research phase. Those four methods are: Define Objectives and Requirements, Build the DSM, DSM Analysis and Activity Structuring, and Align with Project Delivery Models. The model is shown in Figure 14.

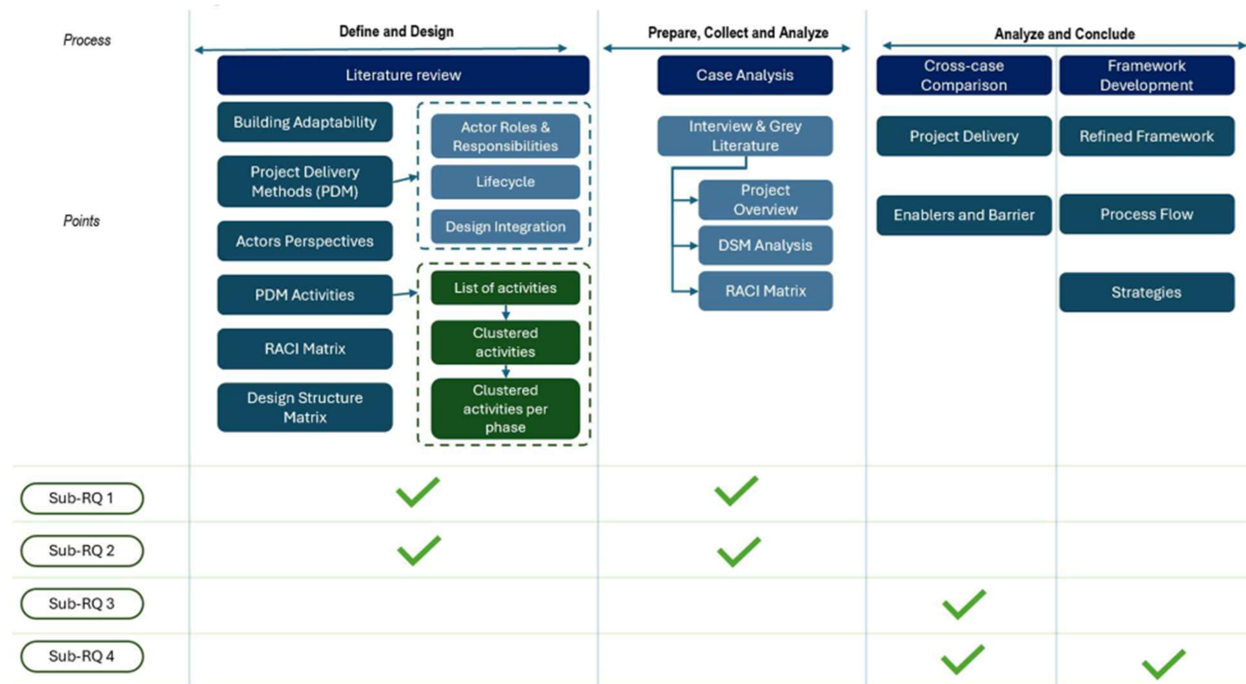


Figure 14 Research Design Framework

3.2. Definition of Key Actor Roles

To ensure the clarity and consistency throughout the case study analysis, this section defines the key actor roles referred to in this research. The construction industry use a wide range of titles and contractual arrangements, therefore, standardizing these terms is essential for a precise comparative analysis. The following definition will be used to describe the primary stakeholders and their function within the project delivery process.

- **Client:** This term refers to the project's commissioning party, owner, and/or primary end-user. In this research, both case studies feature owner-manager clients (a university campus owner and a housing corporation consortium, respectively). Within these client organizations, multiple interests may exist, such as the procurement team may focus on initial capital costs, while the facility management or operational team is concerned with long-term value and flexibility. The Client, as a whole, is the entity that initiates the project, secures funding, and is ultimately responsible for defining the strategic goals for adaptability.
- **Main Contractor:** This role describes a single firm that holds the primary contractual responsibility for delivering the entire project, from design coordination through to final execution. This entity serves as the central point of contact for the client and manages all downstream activities and subcontractors. This model was particularly prominent in Case B, where the contractor also acted as the modular manufacturer.
- **Manufacturer (Modular Manufacturer):** This refers to the specialized organization responsible for the off-site, factory-based production of the building's modular components. This role is distinct from

a general material supplier, as it involves a complex manufacturing and assembly process. In some delivery models, the Modular Manufacturer may be a subcontractor, while in others (like Project B), it may also be the Main Contractor.

- **Specialist Subcontractor:** This is a subcontractor hired for a specific, highly technical scope of work that requires specialized expertise. Examples from the case studies include the Mechanical, Electrical, and Plumbing (MEP) contractor and the façade system installers. The timing of their involvement and the quality of their integration with the core design team are critical factors in the analysis.
- **Architect/Designer:** This role refers to the entity with primary responsibility for the building's conceptual, spatial, and aesthetic design. They often act as the lead coordinator of the design team. The influence and contractual position of the Architect/Designer can vary significantly between projects. In a traditional model, they may lead the design team under a direct contract with the client. In a DB model, such as in Case B, they may be contracted by or work in a consultative capacity to the Main Contractor, aligning their design with predefined system constraints.
- **Technical Consultants/Engineers:** This category includes the various specialized experts who provide critical technical input to the design, but are not the primary conceptual designers. This group is essential for ensuring the technical feasibility, safety, and performance of the building. Key examples from the case studies include the Structural Engineer and the MEP (Mechanical, Electrical, and Plumbing) design consultants. Other consultants in the broader industry, such as quantity surveyors or sustainability auditors, would also fall into this category.

3.3. Case Selection Criteria

The projects being observed are specific projects that share a common characteristic, ensuring a fair comparison at the proper level. The project must follow these criteria:

1. Relevance to Building Adaptability
   The projects must follow the building adaptability principle, such as addressing the modification needs (allowing reconfiguration and repurposing to an extent), minimizing waste, and maximizing the potential use of space. Preferably, the building has been reconfigured, and its components have been changed. However, if not, it can be used in the project's first cycle of project delivery, which guarantees that it can do the adaptability process in the future. The timeline of the project can be seen on Figure 15.

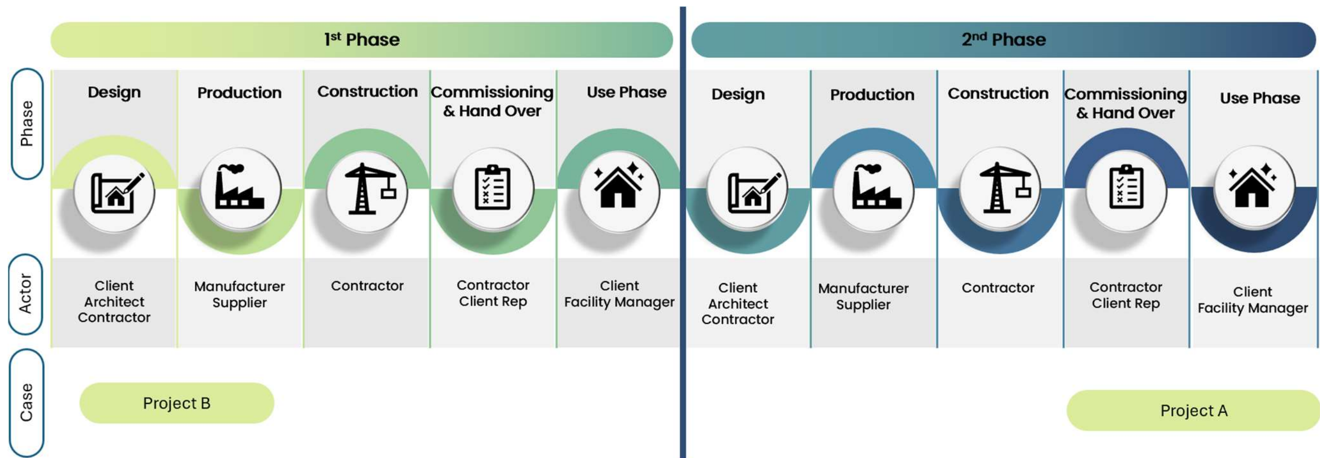


Figure 15 Timeline of project lifecycle: Project A (Office Expansion) and Project B (Relocatable Housing)

2. Diversity of Project Delivery Models
   The project delivery model should vary in each case to make it comparable. However, if all those projects have the same project delivery models, the research can still be conducted by comparing the processes that happened in the projects.

3. Availability of data and stakeholders
   The most important thing to consider is the data availability from stakeholders, since it is the primary data collected. There must be access to interviews with key stakeholders, for instance, project managers and contractors.

3.4. Data Collection

Two types of data collection methods are used to gain an optimal understanding of this research: primary data and secondary data. Semi-structured interviews with adaptable building projects capture the primary data. The interviewees have direct responsibilities for the projects, for example, project coordinators, project managers, or engineers.

This research uses qualitative data collection methods, which capture insights from industry professionals, project data, and comparative case studies. The primary methods are:

1. Literature Review

   Review existing literature on adaptive project delivery models and expansion projects. Deep dive into the relationship between stakeholders, activity, and interdependence.

2. Semi-Structured Interviews

   The semi-structured interview is an exploratory interview used most often in social sciences for qualitative research purposes or to gather clinical data. While it generally follows a guide or protocol that is devised prior to the interview and is focused on a core topic to provide a general structure, the semi-structured interview also allows for discovery, with space to follow topical trajectories as the

conversation unfolds (Zeigler-Hill & Shackelford, 2020). The interviewees are key people in the projects or those who have great responsibility for the project's success. The interview will explore the project challenges, process, stakeholder collaboration, and strategies to overcome the problems. To gain this kind of insight, open-ended questions are selected as a method of conducting interviews, which aim to get a description of key actions, decision points, and coordination steps related to delivering building adaptability.

To explore the relationship between project delivery models and building adaptability in practice, semi-structured interviews will be used with the key stakeholders involved in the case studies, as can be seen in Table 6. These interviews aim to understand the delivery model choices, the roles and perspectives of key actors, and how adaptability considerations were addressed throughout the project lifecycle.

Table 6 Correspondence Details

Project	Participant number	Stakeholder	Role
Project A	A1	Client	Project Coordinator
	A2	Client	Supervisor
	A3	Client	Program Manager
	A4	Main Contractor	Lead Engineer
	A5	Main Contractor	Technical Designer
	A6	Sub-contractor MEP	Installation Coordinator
	A7	Contractor	Project Manager
	A8	Contractor	Site Engineer
	A9	Contractor	Site Engineer
Project B	B1	Client	Location Manager
	B2	Client	Junior Project Manager
	B3	Contractor	Project Engineer
	B4	Contractor	BIM Coordinator
	B5	Contractor	Project Manager
	B6	Architecture	Architecture

3. Project documents

Documents are effective data gathering methods, mainly when events can no longer be observed or when informants have forgotten the details (Bowen, 2009). This method's flexibility allows documents to be analyzed standalone or combined with other methods as supplementary and contextual means of data triangulation and trustworthiness measures (Septiyanto et al., 2023). Examples of project documents are work breakdown structure (WBS), scheduling, design briefs, meeting notes, etc.

3.5. Data Analysis Process

A thematic analysis approach was used to systematically analyze the qualitative data from the semi-structured interviews and project documents. This method was chosen for its flexibility in identifying, analyzing, and reporting patterns (or 'themes') within the data, making it well-suited for an exploratory study of this nature (Braun & Clarke, 2006).

- **Step A: Data Familiarization**

The analysis began with a process of data familiarization, where all interview transcripts and relevant project documents were read and re-read to gain an in-depth understanding of the content. During this phase, interesting features, statements, and concepts from the data were highlighted and labeled with descriptive terms.

- **Step B: Searching for Themes (Categorization)**

Interview transcripts were thematically coded by the researcher using the Gioia methodology (Gioia, 2021), as can be seen in Figure 16, starting with open coding to label first-order concepts. These are informant-centric terms or phrases that closely reflect what interviewees said, such as “The ventilation system required more space than anticipated..." was coded as” The existing space for ventilation is not enough to accommodate the new design”. Furthermore, these first-order concepts are grouped into broader second-order themes. These are researcher-centric categories that help reveal patterns or theoretical insights, such as “Late Technical Coordination Conflicts”. Finally, these themes are synthesized into aggregate dimensions, which represent higher-level constructs that answer the research questions.

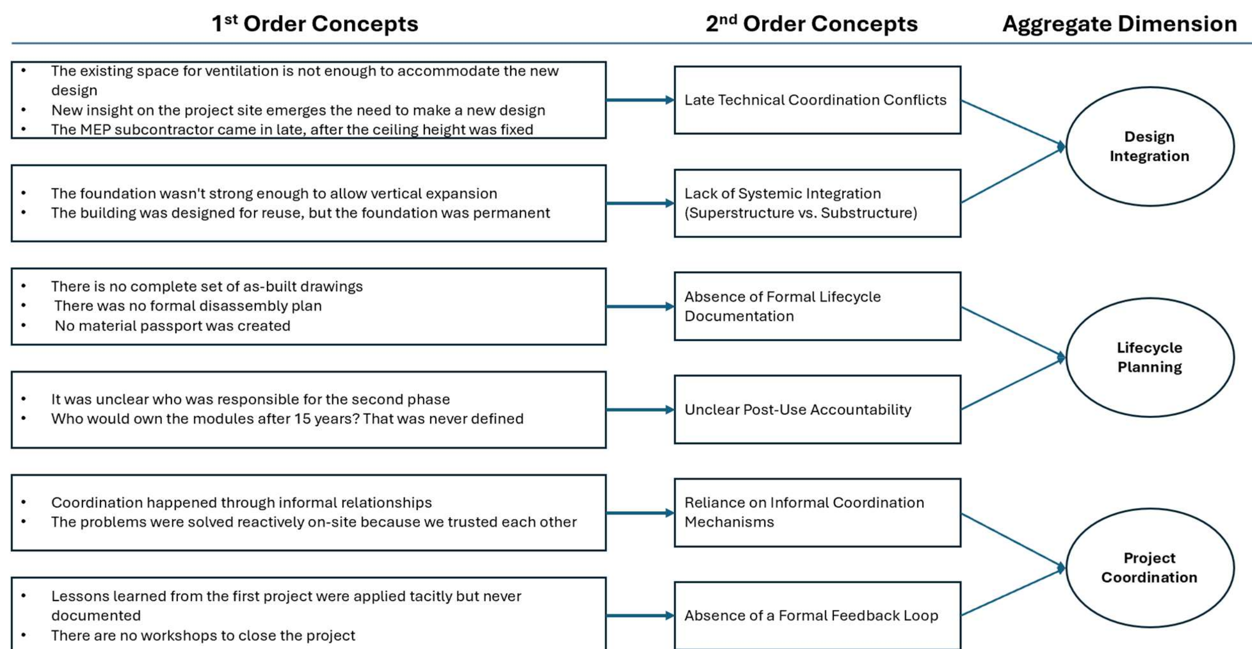


Figure 16 Bottom-up analysis with Gioia

- **Step C: Reviewing and Refining Themes**

The potential themes were then reviewed and refined to ensure they accurately represented the dataset. Some themes were merged, others were split, and some were discarded. This iterative process led to the finalization of the three core analytical themes that form the structure of the cross-case analysis: **(1) Design Integration, (2) Lifecycle Planning, and (3) Coordination**. These themes were validated against the original data to ensure they were coherent, distinct, and captured the essence of the challenges and enablers in delivering adaptable buildings. The resulting themes will be presented and discussed in detail in Chapter 5.

Furthermore, to explore how actor coordination and project delivery strategies influence adaptability in industrialized construction projects, this study uses a comparative case analysis approach. The analysis focused on two projects that have similarities in using modular construction and ambition for adaptability. The objective was to uncover how delivery decisions, sequence flow, and actor coordination contribute to or hinder long-term adaptability.

The data source comprises an interview transcript with key project stakeholders (client, contractor, subcontractors), project data, a RACI matrix, and a DSM matrix. After that, activities were structured into a DSM to capture process dependencies, feedback loops, and isolated sequences. In parallel, RACI matrices were generated to map out coordination and responsibilities. The analysis highlighted where critical deliverables, such as DfD integration or lifecycle documentation, were implemented or postponed.

Patterns from the cases were validated against existing frameworks on collaborative delivery (Engebø et al., 2020), lifecycle-based project planning (Davies et al., 2019) and early contractor involvement (Wondimu et al., 2020). Visual tools, including flowchart diagrams, were used to contextualize outcomes and illustrate implementation pathways. The following analysis was synthesized into clustered enablers and barriers, which were categorized based on thematic analysis. This supported a structured cross-case comparison of delivery decisions and their implications for adaptability. Through this process, implementation strategies were formulated, also with the same theme.

The thematic analysis provides qualitative context for more structured DSM and RACI analyses. While DSM maps the 'what' and 'when' of activity dependencies and RACI clarifies 'who' is responsible, thematic analysis reveals the 'why' and 'how', which will explain the underlying patterns of collaboration and fragmentation.

4

Chapter 4: Case Study Findings

4.1 Case Study A – The Office Expansion Project

4.1.1 Project Overview

Project A is located on the TU Delft campus, a living lab for sustainable innovation. In 2017, the Client constructed its original Office Lab 1.0, a modular timber building using CNC-milled Kerto wood modules developed by the Contractor. In 2024, Project A initiated the expansion of Office Lab 2.0, adding 14 horizontally arranged modules using the same system. The documentation can be seen in Figure 17.

Figure 17 Documentation of Project A

The extension project was commissioned by the Client and designed and built again by the same contractor, in collaboration with other subcontractors. The goal was to create a seamless process of modular addition. However, due to foundation capacity limitations, the expansion could only be done horizontally, although early consideration was given to vertical growth. The project followed a highly collaborative delivery approach, with real-time problem-solving on-site, including adaptations to ventilation systems, reuse of old façades and interior components, and adjustments to ceiling heights and ducting routes.

Project A illustrates how modular systems, though technically possible, require strategic delivery planning and proper documentation to remain adaptable over time. As such, the project offers important insights into how initial modular goals can be (or cannot be) translated into adaptive implementations.

4.1.2 Delivery Activities & Actor Coordination Analysis

The formal organizational chart can be seen in the Figure 18, which Client has a line of coordination for Architect, Structural Engineer, MEP Engineering and General Contractor. The General Contractor, in this case, the Contractor, is responsible for managing the execution of the project, including manufacturing, on-site assembly, and installation. However, they are not doing it alone but distributing the work and risk to specific stakeholders who have the capabilities to do it properly.

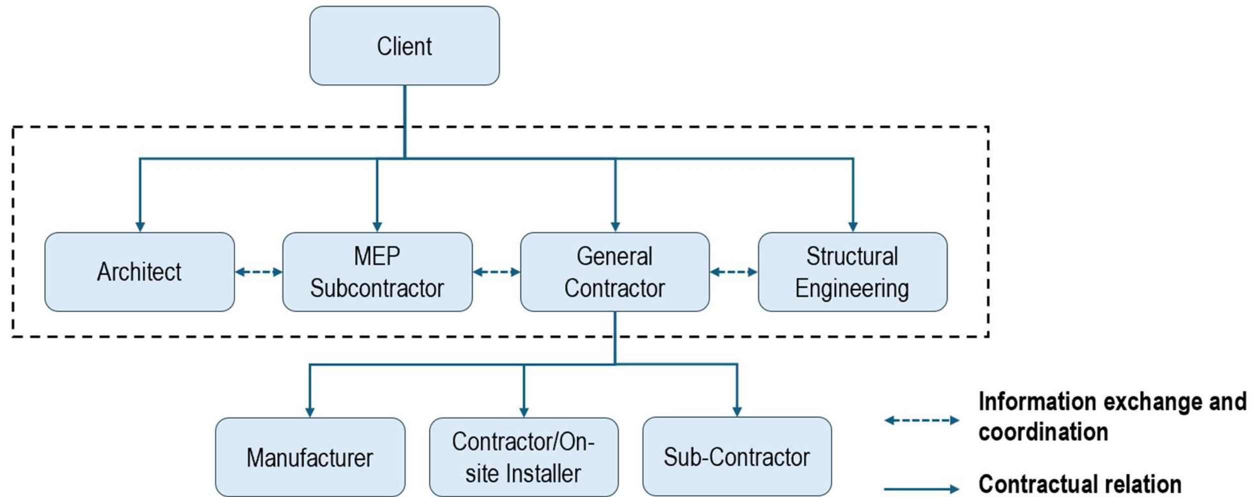


Figure 18 Organizational Chart of Project A

The ambition of Project A is to build an adaptable building was planned from the beginning of the project. However, there is no specific pathway that they follow to control the expansion. The activity list from the previous chapter is used to map the specific activities that the project should do. From the interview and document analysis, the insight from the project is summarized in Table 7.

Table 7 Activity Analysis of Project A

No.	Activity Name	Execution Status	RACI				Refined Observations / Interview Insights
			Client	Contractor	Specialized Contractor	Architect	
1	Establish project intent and adaptability goals	Modified	R	C	I	I	The project's main goal was to build an adaptable office building. However, the initial project definition did not specify or contractually mention this.
2	Select the delivery method and define responsibilities	Informal	R	C	I	C	Design and Build coordinated by the Contractor.
3	Appoint key design and execution stakeholders	Informal	R	C	I	C	Involvement timing varies for some stakeholders, like Specialized Sub-contractor, which came in late, after major layout and ceiling dimensions had already been fixed.

No.	Activity Name	Execution Status	RACI				Refined Observations / Interview Insights
			Client	Contractor	Specialized Contractor	Architect	
4	Develop spatial layout and modular configuration	Fully executed	C	R	I	R	The Contractor using the same modular system from Office Lab 1.0, but without adjusting to the new user needs, for example, different ceiling clearances and ventilation.
5	Plan the structural system and floor/foundation strategy	Partially addressed	C	R	I	C	The existing concrete foundation was reused, but it was not strong enough to hold vertical expansion. Therefore, the lab was expanding horizontally. This unplanned future modification was limiting adaptability options.
6	Design building services (MEP)	Modified	I	C	R	C	A new MEP system was installed, but the ceiling height became a constraint. The lack of early coordination led to poor execution.
7	Coordinate layout and modular constraints	Iterated	I	C	R	C	On-site adjustments were necessary due to MEP sub-contractor's late involvement.
8	Integrate disassembly and reuse requirements (DfD)	Lacking documentation	A	C	I	I	Adaptability was desired but never documented. Modules reused Office Lab logic, but no formal disassembly detailing or relocation plan was established.
9	Conduct constructability and feasibility reviews	Minimal	A	I	I	C	No structured constructability review occurred. Issues were addressed reactively, with missing design history from the Office Lab resulting in design blind spots.
10	Procure systems, materials, and subcontractors	Informal procurement	A	C	I	I	Procurement decisions were based on informal agreements and previous working relationships, which streamlined delivery but lacked clarity on risk distribution.
11	Fabricate modules and prepare off-site logistics	Fully executed	C	R	I	I	Modules were fabricated according to the manufacturer's standard production. Coordination and logistics were efficient due to the reuse of known processes and module types.
12	Prepare site and foundations	Fully executed	C	R	I	I	Site preparation was conducted using the same setup as Office Lab 1.0, including crane access and power connections, which helped avoid on-site conflicts and redesign.

No.	Activity Name	Execution Status	RACI				Refined Observations / Interview Insights
			Client	Contractor	Specialized Contractor	Architect	
13	Deliver and install modules on site	On-site adaptations	C	R	I	C	Overall, the installation went smoothly, but some adjustments were needed on-site due to service clashes and fitting tolerances.
14	Test systems and perform commissioning	Partial	I	C	R	C	Systems were tested and adjusted during commissioning, but not pre-modeled or simulated in earlier phases.
15	Handover documentation and plan post-occupancy support	Missing	A	C	R	C	There was no structured project phase documentation or digital archive, and future reuse or modification is not tracked.

The coordination between stakeholders in Project A is characterized by close relations, particularly between Client A and the Contractor, a commitment by their **informal agreement** to jointly establish a sustainability office. The Client acts as both the commissioner and the future user. Client A had a long-standing partnership with the Contractor, a modular building company that designed and delivered both the original Office Lab 1.0 (in 2017) and the new expansion (Office Lab 2.0). The Contractor maintained ownership of the original design system and manufacturing logic, positioning them as both architect and modular system provider.

However, this has made the contract informal and non-binding, much like any other commercial contract. For example, when the project finishes, the contractor needs to hand over the as-built drawings to the client so they can get the completion payment, but the the Contractor did not do that, and still got the payment.

Table 7 also show the RACI matrix for every activity that every stakeholder is doing. From the table, the line of responsibility can be seen, and the unperformed actors can be identified. The RACI analysis for the Client Office Lab 2.0 project reveals a separation and informal distribution of responsibilities, which is consistent with the ad hoc delivery structure observed throughout the project. the Client , as the project owner and user of Project A, was responsible for the earliest (activities 1-3) and latest stage (activities 15) but had limited influence on the technical aspects. In the first stage, the Client is responsible for establishing adaptability goals, selecting delivery methods, and appointing key stakeholders. However, this adaptability decision was not formalized in contracts. The Contractor and MEP Contractor were involved based on their previous collaboration in Project A Office Lab 1.0, with the Contractor playing a consulted (C) and informed (I) role. For example, MEP Contractor was only informed during the early phase but later became responsible for designing and executing MEP systems (Activities 6, 7, and 14). The late involvement of the MEP Contractor affects the site execution and requires some site adjustments.

The Contractor leads responsibility (R) for core design and execution activities (Activities 4-5, 11-13), as they have primary experience from the earlier project life cycle. However, the adaptability aspect, such as disassembly strategy (Activity 8) and lifecycle documentation (Activity 15), was not clearly assigned to any actor, resulting in no formal documentation for future reuse. So, while the modularity delivered efficiency, the long-term adaptability principle was not planned and executed well enough.

The architect did not have any major influence on the whole project life cycle. Although consulted during layout and technical coordination, the architect was not assigned responsibility for any critical activities. This also confirms the informal project structure, where coordination occurred through relationships rather than a formal, contract-based approach.

In summary, the actor-role mapping reveals that adaptability-related outcomes in the Client case were not limited by technical capability, but rather by the lack of clearly defined assigned responsibilities across the project lifecycle. This absence of a formal line of collaboration, combined with the late engagement of the technical actor, resulted in project delivery that was able to finish short-term goals (Office Lab 1.0) but underperformed on the adaptability project (Office 2.0).

4.1.3 DSM Analysis

To understand how coordination and task sequencing influenced adaptability in the Project A Office Lab 2.0 project, a DSM was constructed in the Table 8. This matrix captures the observed dependencies between activities based on interview data and document analysis. By visualizing these interdependencies, the DSM provides insight into how delivery processes were structured and whether key aspects of adaptability, such as modularity, disassembly, or lifecycle reuse, were effectively embedded throughout the project's flow.

Table 8 DSM Matrix of Project A

No.	Activity Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Establish project intent and adaptability goals	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Select delivery method and define responsibilities	2	0		0	0	0	0	0	0	0	0	0	0	0	0	0
3	Appoint key design and execution stakeholders	3	0	0		0	0	0	0	0	0	0	0	0	0	0	0
4	Integrate disassembly and reuse requirements (DfD)	4	1	0	1		0	0	0	0	0	0	0	0	0	0	0
5	Develop spatial layout and modular configuration	5	0	0	0	0		0	0	0	0	0	0	0	0	0	0
6	Structural design for adaptability	6	0	0	0	0	0		0	0	0	0	0	0	0	0	0
7	Design building services (MEP)	7	0	0	0	1	1	0		0	0	0	0	0	0	0	0
8	Coordinate technical layout and system	8	0	0	0	0	0	1	1		0	0	0	0	0	0	0
9	Conduct constructability review and iteration planning	9	0	0	0	0	0	0	0	0		0	0	0	0	0	0
10	Procure systems, materials, and subcontractors	10	0	0	0	0	1	0	1	0	0		0	0	0	0	0
11	Fabricate modules and prepare off-site logistics	11	0	0	0	0	0	0	0	0	0	0		0	0	0	0
12	Prepare site and foundations	12	0	0	0	0	0	0	0	0	0	0	0		0	0	0
13	Deliver and install modules on site	13	0	0	0	0	0	0	0	0	0	0	1	0		0	0
14	Test systems and perform commissioning	14	0	0	0	0	0	0	1	0	0	0	0	0	1		0
15	Handover documentation and plan post-occupancy support	15	0	0	0	0	0	0	0	1	0	0	0	0	0	1	

Insight for Adaptability

1. Early planning activities will define the adaptability outcomes

The activities in the planning phase (activities 1-3) have a significant impact on the adaptability outcomes. Although it is on the activity list and the client has completed it, there are no or limited dependencies from planning activities to technical design activities (4-8). This highlights the disconnect between adaptability as a concept and its practical application. For example, the client wants an adaptable office that can expand in

the future, whether expand horizontally or vertically, but this was not formally translated into structural foundation capacity, MEP flexibility criteria, or lifecycle documentation.

> *"The foundation wasn't strong enough to allow vertical expansion, which was initially considered an option."*

> *"Design modules with extra ceiling space now to accommodate future technical needs."*

2. Coordination and construction reviews are unlinked

Activity 9 (Constructability and iteration planning) depends on system and structural inputs. However, DSM shows that no backward links to DfD. This linear flow indicates that constructability was treated as a one-off check, rather than a feedback tool for refining the modular detailing. This also aligns with the observation that many issues were addressed reactively, especially when MEP sub-contractor had to adjust their technical services due to uncoordinated ceiling dimensions.

> *"We had to adjust the design multiple times because of new insights, which delayed the process."*

The sub-activity in Activity 8 is clash detection and system routing, which will help minimize imprecise modular shapes that require on-site adjustments. In the Client case, they need to conduct a constructability review early on or iterate to accommodate system installation issues, rather than simply coordinating after the layout is finalized.

3. Technical Issue in procurement, fabrication and execution

The activity list includes the DfD reference during execution. However, these features come from informal flexibility, not formal adaptability planning. It shows from the DSM matrix that Activity 10 (Procurement) does not depend on Activity 8 (DfD). Additionally, Activity 11 (Fabrication) flows into installation but not back to the design activity.

> *"The ventilation system required more space than anticipated, leading to on-site adjustments."*

Execution actors allowed for adjustment, but the system was not designed to adapt. True adaptability requires back-looping handover, commissioning, and fabrication data into system definition.

4. Disconnection of project lifecycle continuity

Handover and post-occupancy planning exist, but they are disconnected from the lifecycle strategy. The DSM indicates that they are organizational endpoints, rather than contributors to future adaptability, as demonstrated by handover and post-planning (Activity 15), which are not directly connected to the project cycle. Interviews confirmed that as-built documentation and reusability records were incomplete.

> *"We didn't have a complete set of drawings and details of the as-built situation."*

Moreover, the activity table includes terms like "Material Passport" and "Digital Twin," but the DSM indicates these had no operational ties to planning or procurement.

Without clear lifecycle closure, even a modular project risks becoming a fixed asset. Closing the loop, such as through reuse plans, document handover, and post-use feedback, must be designed rather than adjusted during execution.

4.2 Case Study B – The Relocating Housing

4.2.1 Project Overview

The Project B, as can be seen in Figure 19 Project B , is a modular housing project located in Hilversum, the Netherlands, which was initiated to address the need for affordable rental housing in the region. The project is built on Diependaalselaan, a site previously used as a temporary event space, and will provide approximately 379 relocatable social rental homes. The project also includes public space improvements, communal green areas, and a sustainable energy strategy using all-electric systems. Due to the permit regulation from the municipality of Hilversum, these houses are expected to be relocated elsewhere after 15 years.

Figure 19 Project B Concept drawings

The homes are built using dry-stacked modular units, which are fabricated off-site at Manufacturer B's factory and transported to the site for on-site assembly. The design fulfills the requirements of permanent housing, including acoustic and fire safety regulations, while also allowing for full disassembly and reuse. Even though the superstructure is reusable, the foundation is site-specific and not intended to be relocated.

Project B project is a suitable case for this thesis, as it combines an adaptability goal (relocation after the use phase) with a project delivery strategy that requires complex coordination to align with building adaptability.

4.2.2 Project Overview & Actor Coordination Analysis

The Client contracted the responsibility for building to the Contractor, a Manufacturer and Contractor company, with the prior design by the Architect. The contractor must manage off-site manufacturing by assembling modular elements in the factory, such as stairs and MEP systems, sourced from specialized subcontractors. The organizational chart can be seen on the Figure 20.

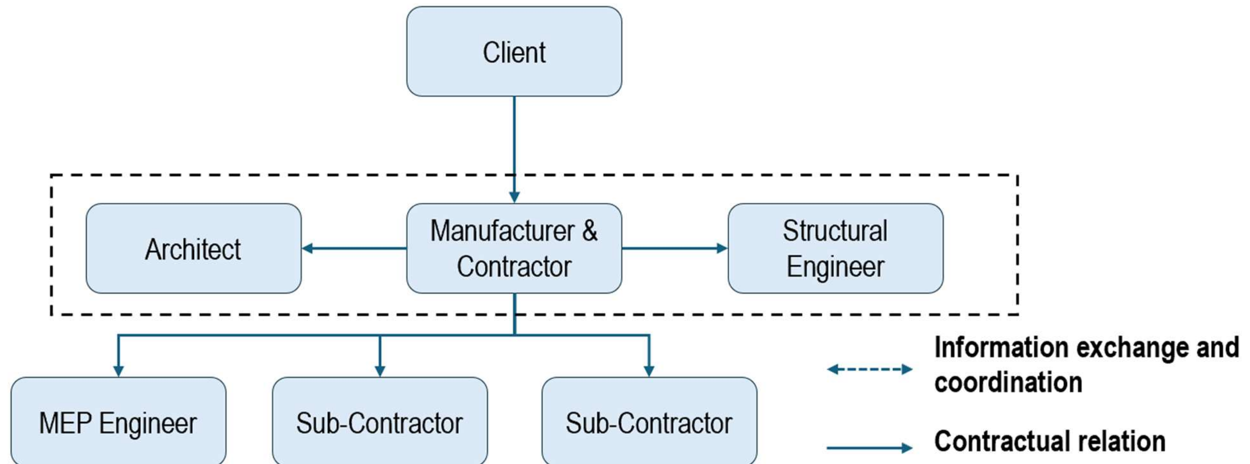


Figure 20 Project B's organizational chart

The analysis in the RACI matrix per activity can be seen in Table 9. The delivery process for Project B followed a structured but iterative flow, typical of modular construction projects with early contractor involvement. The project began with the client consortium commissioning the Architect to develop a conceptual design that aligned with municipal planning requirements and the client's ambitions for the temporary housing site.

Table 9 Activity Analysis of Project B

No.	Activity Name	Execution Status	RACI				Refined Observations / Interview Insights
			Client	Contractor Manufacturer	Architect	Specialized Contractor	
1	Establish project intent and adaptability goals	Completed	A	C	I	I	Driven by a 15-year municipal permit, adaptability was reflected in a relocation goal.
2	Select the delivery method and define responsibilities	Completed	A	C	I	I	A D&B model was selected, with early contractor involvement.
3	Appointing key design and execution stakeholders	Completed	A	C	C	C	The client assigned the responsibility for design coordination to the Main Contractor. This structure leveraged the Contractor's deep expertise in its modular system and allowing them to lead the technical integration of the design
4	Develop spatial layout and modular configuration	Completed	C	R	R	C	The Contractor proposed a standard design to the architect that limits layout design, but ensures delivery efficiency and adaptability.
5	Plan the structural system and floor/foundation strategy	Completed	C	R	C	R	The foundation was designed to hold 3-story buildings (3-layer stacking), but it was fixed and not for future disassembly or reuse.
6	Design building services (MEP)	Partial	I	R	I	I	MEP was embedded in the module to ensure fast site installation. However, future adaptations were not modeled, which will reduce long-term flexibility.
7	Coordinate layout and modular constraints	Completed	I	R	C	I	There are weekly design meetings to ensure progress and coordination in the design.

No.	Activity Name	Execution Status	RACI				Refined Observations / Interview Insights
			Client	Contractor Manufacturer	Architect	Specialized Contractor	
							However, adaptability scenarios were not explicitly considered.
8	Integrate disassembly and reuse requirements (DfD)	Partial	A	C	I	I	Modules were designed for dry disassembly, but the layout plan for relocation was not finalized due to some future uncertainties regarding site relocation.
9	Conduct constructability and feasibility reviews	Completed	C	R	C	C	The Contractor conducted internal constructability checks
10	Procure systems, materials, and subcontractors	Completed	A	C	I	I	Subcontractors for stairs, façade elements, and connections were integrated via the Contractor's standard vendor network.
11	Fabricate modules and prepare off-site logistics	Completed	I	R	I	I	Off-site fabrication occurred at the Contractor's Dutch facility. Logistics were seamless due to in-house experience, but component reusability tracking was not reported.
12	Prepare site and foundations	Completed	C	I	I	I	Site preparation was conventional. The foundation was permanent. Therefore, it is not able to support adaptability in terms of foundation relocation
13	Deliver and install modules on site	Completed	I	R	C	I	Installation occurred over a short period with precise planning. However, minor adaptations were needed on-site to fit stair modules
14	Test systems and perform commissioning	Completed	C	R	I	I	Standard commissioning procedures were followed. As the building met permanent building codes, testing exceeded temporary-use expectations.
15	Handover documentation and plan post-occupancy support	Incomplete	A	C	I	I	No clear data exists for future relocation. Responsibility for reuse remains undefined, hence it potentially becomes a risk for the client once the 15-year permit ends.

While the project generally followed a linear process, there were important feedback loops (between the Contractor and the Design team) related to staircase layout, acoustic details, and fire code compliance. These loops influenced material and layout choices, showing how tightly linked technical adaptability and delivery structure can be in practice.

The project was delivered through a tendered Design & Build (D&B) contract with significant early contractor involvement. This approach shares strong characteristics with the *Bouwteam* model, a collaborative PDM commonly used in the Netherlands. Although not a formal IPD contract, the Contractor's early involvement allowed them to work closely alongside the Architect during the initial design phase. This enabled the Contractor to align the conceptual design with the constraints of their modular system, which is a key factor in translating the Architect's vision into a technically feasible design.

Other key stakeholders included:

- Subcontractors for façade systems, interior finishes, and staircases (coordinated by the Contractor)

- Structural engineer appointed as a sub-consultant by the Contractor, who collaborated closely with the Architect to ensure the design was structurally feasible.
- Utilities and service consultants, responsible for ensuring connections met municipal standards

Stakeholder interaction was characterized by weekly coordination meetings and continuous email exchanges, particularly during the design optimization phase. The project required a high degree of coordination between architectural intent and modular constraints, especially in terms of fire safety, circulation (for example, stair and corridor placement), and acoustic performance.

This case is an example of a client-led procurement approach with contractor-led delivery details, which provides a rich context for analyzing how stakeholder alignment (or misalignment) influences the implementation of building adaptability.

The RACI analysis of the Project B project, which can be seen on Table 9, reveals a technically driven delivery structure, with the Contractor as the primary responsibility (R) for most mid-phase activities, particularly those related to technical design, fabrication, and execution (Activities 4-14). The centralized coordination is evident in the D&B model, where the Contractor assumes roles early in the design and execution phases. Despite its capabilities, the Contractor was not held accountable for future adaptability or relocation.

The Client remains accountable (A) for the project and sets its adaptability goals (Activities 1-3). Then, they are involved during the technical and execution stages by being consulted (C) or informed (I). The client was also accountable for post-occupancy planning (Activity 15), yet no handover or reuse plan was developed. The architect was responsible (R) only for the initial layout (Activity 4), and consulted on technical design and coordination. Their limited involvement in construction or lifecycle activities suggests that their contribution was primarily aesthetic or spatial, not strategic.

The Specialized Contractor (in this case, the Structural Engineer) was responsible (R) for the structural and foundation planning (Activity 5), but otherwise consulted (C) or informed, reflecting a narrow design role. Notably, the foundation design was permanent, which directly conflicted with the project's adaptability intent.

In summary, the RACI matrix reveals an efficient but vertically siloed delivery structure. While activities were executed effectively, accountability for lifecycle adaptability was unassigned. This organizational gap mirrors the conclusions from the DSM and activity analysis, that adaptability was engineered into components but not governed or documented beyond the project deliverables. This reinforces the need for clear accountability in post-occupancy planning, especially in modular projects intended for future relocation.

4.2.3 DSM Analysis

To understand how design and delivery activities were coordinated in the Project B project, a DSM, as can be seen in the Table 10, was developed based on interview data, stakeholder roles, and supporting data.

Table 10 DSM Matrix of Project B

No	Activity Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Establish project intent and adaptability goals	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Select delivery method and define responsibilities	2	0		0	0	0	0	0	0	0	0	0	0	0	0	0
3	Appoint key design and execution stakeholders	3	0	0		0	0	0	0	0	0	0	0	0	0	0	0

No	Activity Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Develop spatial layout and modular configuration	4	1	1	1		0	0	0	0	0	0	0	0	0	0	0
5	Plan structural system and floor/foundation strategy	5	0	0	0	1		0	0	0	0	0	0	0	0	0	0
6	Design building services (MEP)	6	0	0	0	1	0		0	0	0	0	0	0	0	0	0
7	Coordinate layout and modular constraints	7	0	0	0	1	0	1		0	0	0	0	0	0	0	0
8	Integrate disassembly and reuse requirements (DfD)	8	0	0	0	0	0	0	0		0	0	0	0	0	0	0
9	Conduct constructability and feasibility reviews	9	0	0	0	0	1	0	1	0		0	0	0	0	0	0
10	Procure systems, materials, and subcontractors	10	0	0	0	0	0	0	0	0	1		0	0	0	0	0
11	Fabricate modules and prepare off-site logistics	11	0	0	0	0	0	0	0	0	0	1		0	0	0	0
12	Prepare site and foundations	12	0	0	0	0	0	0	0	0	0	0	1		0	0	0
13	Deliver and install modules on site	13	0	0	0	0	0	0	0	0	0	0	0	1		0	0
14	Test systems and perform commissioning	14	0	0	0	0	0	0	0	0	0	0	0	0	1		0
15	Handover documentation and plan post-occupancy support	15	0	0	0	0	0	1	0	0	1	0	0	0	0	1	

Insight on Adaptability

The DSM for Project B reveals a relatively linear progression of activities, with few feedback loops or overlapping dependencies. While this structure may suggest a streamlined delivery process, it also exposes several adaptability gaps that limit the project's long-term flexibility:

1. The activities are sequential and not iterative

The DSM confirms that Design building services (MEP) (Activity 6) and Coordinate layout and constraints (Activity 7) depended on modular layout (Activity 4), and that early decisions were shaped by the structural system (Activity 5). However, DfD (Activity 8) appears isolated, it depends on design coordination but does not feed back into structural or MEP development. This suggests that DfD was reactive, rather than being used to guide design from the start.

2. Lifecycle Closure Missing

Commissioning and handover (Activities 14 and 15) are not connected to the rest of the matrix. There are no forward or backward links from early planning to final documentation or reuse strategy. This reflects findings from interviews, where lifecycle handover and digital documentation were not formalized in the initial planning.

Although the Project B project adopted a modular and relocatable system in principle, the DSM structure reveals a gap between ambition and project delivery. DfD and reuse were scoped late, lifecycle goals lacked downstream integration, and the linear process limited opportunities for iteration. Strengthening adaptability in future projects will require earlier embedding of DfD into layout and system design.

5

Chapter 5: Cross-Case Comparison and Findings

This chapter presents further data analysis from the previous sections, which aims to achieve two goals: to compare the two case studies and to synthesize the findings into a coherent conceptual framework. The comparison of Project A and Project B cases is based on project delivery context, activities analyzed through the DSM matrix, actor coordination assessed through the RACI matrix, and adaptability factors. Insights from comparison are then used to develop a new project delivery framework for adaptable modular buildings, which covers the process flow, activity checklist, and stakeholder coordination.

From this analysis, three central themes emerged as the most critical determinants of a project's ability to translate adaptability from an abstract goal into a tangible outcome. These themes consistently appeared across both projects, highlighting fundamental challenges and opportunities in current practice. The three emergent themes are:

1. **Design Integration:** This theme focuses on the collaboration and coordination between key design disciplines, specifically the architect, structural engineer, and MEP specialists. It examines how the timing and quality of their interactions influence the technical feasibility, constructability, and inherent capacity for future change of the building. Effective design integration ensures that adaptability is engineered into the system from the start, rather than being compromised by siloed workflows and late-stage coordination conflicts.
2. **Lifecycle Planning:** This theme addresses the extent to which a project looks beyond the initial design and construction phases to formally plan for the building's entire lifespan, including future use, adaptation, and end-of-life scenarios. It encompasses crucial activities, such as creating formal lifecycle documentation (for example, disassembly guides, material passports), assigning clear post-use responsibilities, and establishing mechanisms for capturing and reusing knowledge across project phases. A lack of lifecycle planning was identified as a primary barrier to achieving long-term adaptability, even in technically modular systems.
3. **Project Coordination:** While Design Integration focuses on the technical design team, this broader theme refers to the overall project delivery structure, decision-making protocols, and the management of information flow among all key stakeholders (client, contractor, suppliers). It examines how formal and informal mechanisms for coordination influence the project’s capacity to achieve its goal of adaptability.

The remainder of this chapter will use these three themes as a structural lens to analyze and compare the delivery processes, stakeholder roles, and adaptability outcomes of Case A and Case B. By examining how

each project navigated the challenges within these themes, key patterns of success and failure can be identified, forming the empirical basis for the framework developed in Chapter 6.

5.1 Cross-Case Comparison

To get new insight, a pattern is being analyzed from the two cases, especially in terms of delivering adaptability. The comparison encompasses the delivery context, activity dependencies, and RACI matrix as key comparable elements.

To substantiate the different contexts in the project, an organizational chart and a table have been created with relevant project information. The information is based on interviews and project information provided by stakeholders and external sources, such as the internet. This information will help to understand the project context, as can be seen in the Figure 21 and the Table 11.

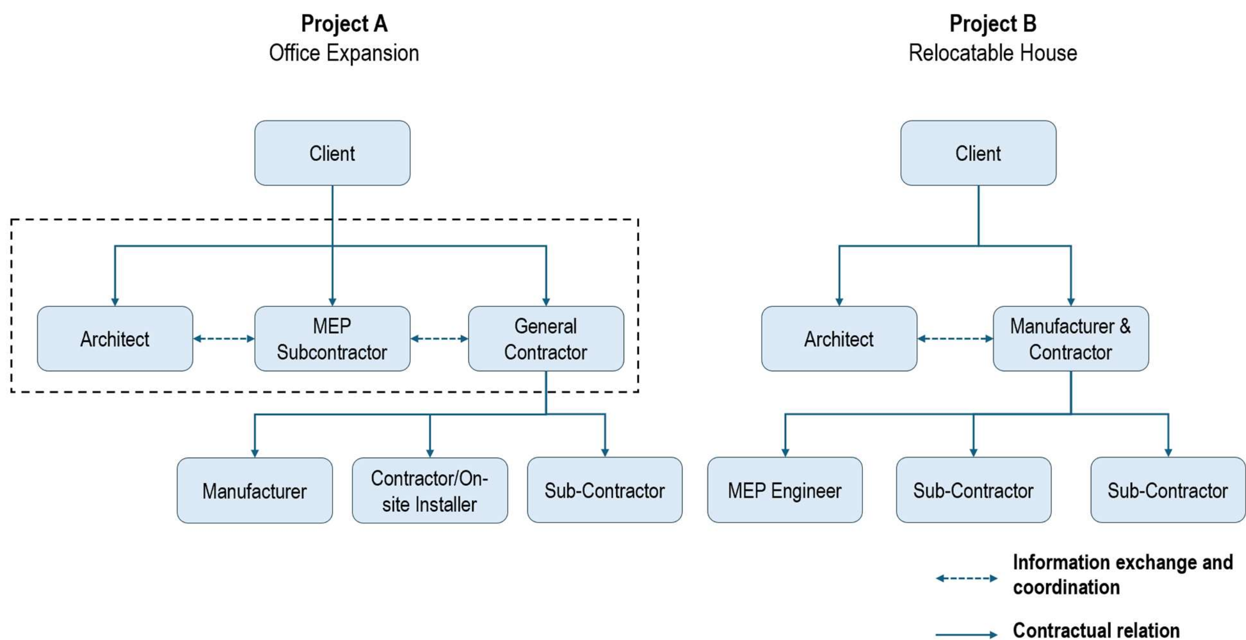


Figure 21 Organizational chart comparison

Table 11 Project Delivery Contexts

Aspect	Project A	Project B
Project Type	Modular office expansion for research campus	Modular mixed-use development with residential and social facilities
Delivery Model	Client-led with layered contracting, partial Early Contractor Involvement	Developer-led, turnkey with DB approach, with limited public-sector interference
Key Actor Types	Client, Architect, Subcontractor, General Contractor, Manufacturer, On-site Installer	Client, Architect, Subcontractor, General Contractor, Manufacturer
Public or Private Client	Semi-public (TU Delft affiliated)	Private developer

Aspect	Project A	Project B
Modular Adaptability	Horizontal expansion, design for off-site prefabrication	Future relocation and rearrangement, designed for stacking and spatial adaptability
Reuse Strategy	Reuse of internal wall panels. The Modules was reused onsite	Reuse of modules in future phases or other building developments
Governance Style	Collaborative and experimental	Market-driven
Design Process Ownership	User-focused, but coordinated by the Contractor	Contractor-coordinated design; the Contractor is responsible for guiding the technical integration of the design to fit their modular system

Key Observations

Some comparable aspects emphasize the difference between Project A and Project B. This difference can be used as a point to understand how they deliver adaptability. First of all, it can be seen that in Project A, modularity was used as an experimental learning tool to enable quick site expansion. This also becomes a drawback, as they are only partially utilizing early contractor involvement. On the contrary, in Project B, modularity was used to accommodate their relocation scenario in the future phase, and adaptability was pre-planned into standardized offerings.

Next, the coordination of Project A by stakeholders demonstrates active engagement from innovative partners and researchers. In contrast, Project B relied on coordination between the contractor and the developer, as they focused on selling the building's function.

In terms of lifecycle, Project A integrated lifecycle thinking moderately, focusing on short-term adaptability potential. Project B embedded lifecycle adaptability in early planning to allow future densification, showing more strategic reuse planning.

DSM Comparison

This section analyzes how delivery activities were structured and sequenced in both case studies using DSM. The comparison highlights differences in flow, feedback loops, and the integration (or neglect) of adaptability considerations. Insight from the DSM comparison is provided in the Table 12.

Table 12 DSM Comparison snapshot

No.	Aspect	Project A	Project B
1	Disassembly activity location	Mid-phase (after use phase)	Early-stage (embedded in concept)
2	Coordination with other designs	Low	Moderate
3	Documented reuse plan	Missing	All parties have it
4	Total interdependencies	Lower (sparser matrix)	Higher (more linked)
5	Feedback loops	2 loops	5+ loops

No.	Aspect	Project A	Project B
6	DfD centrality	Peripheral	Mid-central
7	Post-occupancy preparation	Absent	Weakly embedded

The sequence reveals a primary linear flow done by Project A, with a limited feedback stream. Activities 8 (DfD) were disconnected from early design in terms of adaptability for future expansion. The concept of disconnection also applies to other activities, where there are specific central nodes and isolated nodes. Central nodes are activities that have multiple dependencies, both upstream and downstream. For example, spatial design (Activity 5) is closely connected to structural design, MEP layout, coordination (including routing and clash detection), and fabrication process. Additionally, some activities are isolated or, in this case, have limited dependencies or connections with other activities, such as Activity 15 (Post-occupancy planning). Expansion intent was mentioned, but there was no structured plan for post-use adaptation, handover, or facility management.

Project B shows earlier integration of DfD and constructability reviews. Since they regularly hold meetings, there are opportunities to provide adaptive feedback during the design, as well as during activities such as 'preparing documentation for reuse' and 'modular detailing'. In contrast to Project A, activities in Project B are more interlinked with one another.

Insight from those two cases is that embedding adaptability requires not only early positioning of relevant tasks but also being interlinked throughout the whole project lifecycle.

RACI matrix

This section analyzes how the stakeholders coordinate in activities across both cases using a RACI framework, as can be seen in Table 13. By mapping out the decision-making and coordination roles, the clarity of actor responsibilities in supporting adaptability can be evaluated.

Table 13 Actor role mapping (selected activities)

Activity	Project A	Project B
Define Adaptability Goals	Client (A)	Client (A)
	Architect (C)	Contractor (C)
	Contractor (C)	Architect (C)
Modular Spatial Planning	Architect (R)	Architect (R)
	Client (A)	Contractor (A/C)
	Contractor (C)	Client (I)
Integrate DfD Strategy	Architect (R)	Contractor (A)
	Contractor (C)	Architect (R)
	Client (I)	Client (C)
Off-site Fabrication & Logistics	Contractor (A)	Contractor (A)
	Supplier (R)	Supplier (R)
	Client (I)	Client (I)
Post-occupancy Planning	Architect (C)	Client (A)

Activity	Project A	Project B
	Client (A)	Architect (C)
	Contractor (I)	Contractor (I)

Key Insights

In Project B, the contractor held a stronger leadership role, especially in modular detailing and disassembly design, due to their capabilities of constructing it in their factory. By contrast, Project A relied more on the architect and coordinated with the manufacturer and on-site builder, which creates a longer feedback chain.

Both projects positioned the client as the approved adaptability strategies, however, in Project A, their role in early coordination was more passive, while in Project B, the client actively defined the reuse timeframe and compliance (for example, fire protection) from the start.

Project A showed a weak connection between technical activities (drawing) and documentation responsibilities (as-built). However, Project B mitigated this by giving authority to all stakeholders, especially the contractor, to keep the documentation in the project workflow.

In both cases, the supplier or specialized subcontractor (MEP or façade) was largely consulted rather than being responsible, which results in intense design coordination afterwards and even hinders the execution process.

The RACI maps reveal that clarity of actor roles in modular coordination, DfD integration, and reuse documentation is essential. Projects that embedded adaptability roles early and provided space for a contractor-driven modular strategy (as in Project B) showed stronger coherence. Conversely, misalignments in Project A around who was responsible for lifecycle-related decisions delayed coordination and reduced the leverage of adaptability.

The comparison was then categorized into three themes based on the similarity between the activities, in terms of phase, as can be seen in Table 14.

Table 14 Comparison between Case A and Case B

Theme	Aspect	Case A - Expansion Office	Case B - Relocatable Housing	Synthesis: Key Lesson for Adaptability
Design Integration	Integration Model	Fragmented, siloed integration, late MEP involvement, linear DSM	Contractor-led D&B model, early alignment of modular constraints and design	Holistic integration is important. Avoid both horizontal silos (lack of cross-disciplinary coordination) Integration between adaptable and non-adaptable components needs to be considered. The scope of integration must encompass all critical systems that impact long-term adaptability.
	Key Weakness	No feedback loops, constructability issues led to rework, MEP routes fixed late	Foundation not designed for relocation	
	Lesson	Horizontal silos blocked systemic adaptability	Future usage of the foundation should be considered	

Theme	Aspect	Case A - Expansion Office	Case B - Relocatable Housing	Synthesis: Key Lesson for Adaptability
Lifecycle Planning	Lifecycle Approach	Informal ambition, no formal requirements or deliverables	Clear goal for relocation after 15 years influenced design decisions	Formalized lifecycle governance is imperative. Adaptability must be a contractual deliverable, with clear deliverables (e.g., as-built drawings, DfD manuals), explicit ownership for post-use planning, and a governance structure that persists beyond initial handover.
	Key Weakness	No accountability for lifecycle planning, no reuse documentation	Responsibility for relocation process left undefined: no material passport or guide	
	Lesson	Lifecycle was a hope, not a structured plan	Adaptability goal defined, but execution plan missing	
Project Coordination	Coordination Style	Informal, trust-based coordination relying on relationships	Formal, hierarchical coordination through single contractor	A hybrid coordination model is needed. Combine formal processes and clear hierarchies for contractual definition, documentation, and accountability of lifecycle goals with collaborative communication and trust for early, iterative, and cross-disciplinary dialogue. Embed collaborative routines within a formal contractual framework.
	Key Weakness	Lack of documentation and formal accountability, which causes a loss of project memory	Efficient but rigid: limited early-stage input from consultants	
	Lesson	Short-term agility, but high risk for long-term adaptability	Clear roles and schedule, but constrained innovation due to centralization	

5.1.1 Design Integration

Design Integration, as a theme, examines the quality and timing of collaboration between key technical disciplines. For adaptable buildings, where the interaction between architectural form, structural systems, and MEP services is crucial for future flexibility, effective integration is paramount. A comparison of Case A and Case B reveals two distinct approaches to design integration, each with its consequences for achieving adaptability goals. Case A demonstrates a fragmented, reactive process, while Case B showcases a more integrated but still incomplete model.

Case A: The Office Expansion

The delivery of the Campus Lab expansion was characterized by a fragmented approach where design disciplines operated in relative silos. This is most evident in the late and poorly defined involvement of the MEP subcontractor. The RACI analysis (Table 7) shows that while the MEP team was eventually made Responsible (R) for designing and executing their system (Activity 6), their initial involvement was minimal. They were brought in after key decisions about the modular layout and ceiling dimensions had already been made, creating a costly knowledge gap.

This lack of early integration is visualized in the project's DSM (Table 8). The workflow is largely linear, with a notable absence of feedback loops from construction and constructability reviews back to the core design activities. For instance, Activity 9 (Conduct constructability review) shows no dependency on, nor does it feed back into, the DfD requirements (Activity 8) or MEP design (Activity 6). This linear process meant that constructability was treated as a late-stage check rather than an iterative design driver.

The consequences of this fragmented approach were tangible, leading directly to on-site rework and compromises on adaptability. As one project participant noted, the lack of early coordination led to unforeseen spatial conflicts:

"The ventilation system required more space than anticipated, leading to on-site adjustments."

These reactive adjustments not only caused delays but also constrained the building's future adaptability by fixing MEP routes in a way that had not been planned for. In essence, the siloed workflow prevented the project from embedding adaptability at a systemic level, resulting in costly onsite adjustments.

Case B: The Relocatable Housing

In contrast, the Relocatable Housing project utilized a more integrated, contractor-led Design & Build (D&B) model. The contractor, also being the modular manufacturer, played a central role from the early stages. The RACI matrix (Table 9) confirms this, showing the contractor as Responsible (R) for most of the core technical design and execution activities, from spatial layout (Activity 4) to fabrication (Activity 11).

This centralized coordination allowed for a highly efficient design process. The contractor could immediately align the architectural concept with the constraints and capabilities of their standardized modular system, ensuring that the design was buildable and optimized for off-site manufacturing. This proactive integration minimized the risk of on-site clashes and rework, as seen in Case A.

However, the integration in Case B was not holistic. While the superstructure was masterfully integrated for disassembly and reuse, a critical blind spot existed in the integration with the substructure. The foundation was designed as a permanent, site-specific element, directly conflicting with the project's primary goal of adaptability, which was to relocate after 15 years. This critical oversight was a direct result of the design scope, which treated the foundation as a separate problem to be solved only for the initial use phase.

Comparing these two cases provides a clear lesson: effective design integration for adaptability must be holistic. Case A suffered from horizontal silos, where disciplines were not coordinated effectively across the project timeline, which led to rework. Furthermore, Case B avoided these horizontal silos through a contractor-led model but did not prepare for the adaptable foundation.

This comparison reveals that simply choosing an integrated delivery model like D&B is not enough. The scope of integration must be explicitly defined to include all critical systems that impact the long-term adaptability goal. The true adaptability of the entire building system can only be achieved if everyone on the team shares the same perspective and formalizes it through administration (for example, project planning or a project charter).

5.1.2 Lifecycle Planning: Ambition vs. Reality

Lifecycle planning encompasses the strategies and processes put in place to manage a building's future, from its ongoing use to its eventual disassembly, relocation, or reconfiguration. While both Case A and Case B were conceived with adaptability in mind, a comparative analysis reveals a significant gap between their lifecycle ambitions and the reality of their planning. This gap demonstrates that without formal documentation and clear accountability, adaptability goals can remain unrealized.

Case A: The Office Expansion

The Campus Lab project was initiated from an ambition for future flexibility, with stakeholders verbally expressing a desire for both horizontal and vertical expansion. However, this ambition was never translated into formal project requirements or deliverables. The project suffered from two critical lifecycle planning failures: unclear accountability for post-use planning and a complete absence of structured reuse documentation.

The RACI analysis (Table 7) highlights this ambiguity. While the client was technically Accountable (A) for defining the project's goals (Activity 1) and for the final handover (Activity 15), there was no formally assigned responsibility for creating or managing a long-term lifecycle plan. This lack of ownership had direct physical consequences. The ambition for future vertical expansion, a key adaptability feature, was never engineered into the project's foundation. As one participant revealed:

"The foundation was not strong enough to allow vertical expansion, which was initially considered an option."

This quote perfectly captures the project's core failure: adaptability was a "consideration," not a contractual requirement. Furthermore, the final handover lacked any formal documentation to guide future reuse. Key information, such as as-built drawings for the modified MEP systems or disassembly sequences for the modules, was not systematically captured, which hinders any future team's ability to modify or expand the building efficiently. In Case A, the lifecycle was an informal hope, not a structured plan.

Case B: The Relocatable Housing

In contrast to Case A, the Relocatable Housing project was driven by a clear and explicit lifecycle mandate: the building was designed to be disassembled and relocated after its initial 15-year use period. This goal was a core driver from the project's inception and influenced many design decisions, such as the use of dry-stacked modular units and a reusable superstructure. The existence of this project is evidence of life cycle planning.

However, despite this clear end-of-life goal, the project exhibited significant gaps in its process planning. The RACI analysis (Table 9) shows that while the client consortium was Accountable (A) for the initial adaptability goal (Activity 1) and the final post-occupancy support (Activity 15), the responsibility for the process of future relocation was left undefined. Key questions remained unanswered: Who would own the modules after 15 years? Who would be responsible for managing the disassembly and relocation logistics? What documentation would be required to ensure the modules could be successfully recertified and reused elsewhere?

The project successfully delivered a technically relocatable building but failed to deliver a logistically managed reuse plan. There was no formal handover of a material passport, disassembly guide, or digital twin that would facilitate the building's second life. The responsibility for future adaptability was assumed to be implicitly covered but was never contractually assigned, creating a significant risk for the client once the 15-year permit expires.

Synthesis:

The comparison between Case A's informal ambition and Case B's defined but unmanaged goal yields a powerful insight: adaptability requires formalized lifecycle governance.

- **Case A** demonstrates that, without being a contractual deliverable, adaptability remains a vague aspiration that is easily value-engineered out of critical components like the foundation.
- **Case B** shows that even when adaptability is a core project driver, its success is not guaranteed without a clear plan for post-use ownership, documentation, and logistics.

Both cases underscore the same critical lesson: a building's future cannot be left to chance or informal understanding. To be successful, lifecycle objectives must be embedded within the project's contractual framework. This includes defining clear deliverables (for instance, as-built drawings, DfD manuals), assigning explicit ownership for post-use planning, and ensuring that the project's governance structure persists beyond the initial handover. Without this formal structure, the long-term value of adaptability is fundamentally at risk.

5.1.3 Project Coordination: Formal vs. Informal Mechanisms

Project coordination governs the flow of information, decision-making authority, and stakeholder relationships that define a project's delivery. The comparison between Case A and Case B reveals a fundamental tension between informal, relationship-based coordination and formal, process-driven coordination. While both models have distinct advantages, they also present significant risks to achieving long-term adaptability.

Case A: The Office Expansion - Coordination Through Informal Relationships

The coordination model for the Campus Lab expansion was reliant on informal mechanisms and pre-existing relationships. The client and the primary contractor had a long-standing partnership, having worked together on the original building. This "design familiarity" and established trust enabled a highly flexible and agile coordination style, where decisions could be made quickly without rigid, formal procedures. As the analysis in Chapter 4 revealed, this allowed the team to solve problems on-site with a degree of efficiency reactively.

However, this informal approach carried significant risks that ultimately undermined the project's adaptability goals. The reliance on verbal agreements and undocumented decisions created a fragile project memory. Without a formal process to fall back on, critical information was lost or never recorded. For example, the decision not to strengthen the foundation for vertical expansion was a critical choice that was not formally documented, leaving future stakeholders with a building that failed to meet its initial, albeit informal, adaptability potential. The RACI matrix for Case A (Table 7), with its scattered and informally assigned responsibilities, is a clear symptom of this unstructured approach. While informal coordination can be efficient in the short term, it creates long-term vulnerability by failing to produce the robust documentation and clear lines of accountability necessary for future adaptation.

Case B: The Relocatable Housing - Coordination Through Formal Hierarchy

In direct contrast, the Relocatable Housing project operated under a highly structured and formal coordination model. As a market-driven, turnkey project, it featured a clear hierarchical structure: the client consortium held a single contract with the main contractor, who then managed all downstream design, manufacturing, and subcontracting activities. This D&B model created a single point of responsibility, streamlining communication and ensuring that all activities were tightly aligned with the contractor's efficient, standardized production processes.

By centralizing control with the contractor, it potentially limited the innovative input from other specialists, such as the architect or MEP consultants, whose roles were more consultative than collaborative. For

instance, the design was constrained by the contractor's existing modular standard to ensure efficiency, which, while beneficial for execution, may have limited opportunities to explore more innovative or site-specific adaptability solutions. The linear of the DSM for Case B (Table 10) reflects this efficient-but-rigid coordination style, where iteration and cross-disciplinary exploration were minimized in favor of predictable execution.

Synthesis: The Need for a Hybrid Coordination Model

The comparison of these two cases highlights a crucial trade-off. Case A's informal model offered flexibility but lacked the formal structure needed for long-term accountability. Case B's formal model ensured efficiency and accountability but at the potential cost of collaborative innovation.

This leads to a clear conclusion: delivering adaptable buildings effectively requires a hybrid coordination model. Such a model would combine the best of both worlds:

- The formal processes and clear hierarchies of a structured approach to ensure that lifecycle goals are contractually defined, documented, and assigned.
- The collaborative communication and trust of an informal approach to foster the early, iterative, and cross-disciplinary dialogue necessary for innovative problem-solving.

An ideal model does not force a choice between agility and structure. Instead, it embeds collaborative routines (like early-stage workshops and integrated design reviews) within a formal contractual framework that holds all parties accountable for the project's long-term adaptability. This balanced approach ensures that adaptability is not only designed efficiently but is also managed robustly throughout the building’s entire lifecycle.

5.2 Key Findings: Barrier and Enablers to Adaptability

This section focuses on developing the framework based on insights from previous cases. The framework is illustrated in the cover project delivery, showcasing building adaptability and its implementation. The components to implement it consist of stages, enablers, barriers, and strategies. This synthesis framework is proposed for use in a similar project in the future, so it will not only solve the previous case but also others.

5.2.1 Enablers and Barriers

Although modular construction offers the ability to be modified, in terms of project delivery, it still requires specific enablers to ensure the entire process runs smoothly. Conversely, mismanagement of project delivery will become a barrier to efficiently modifying the building. Insight into how the enablers and barriers affect the adaptability process can be seen in the Figure 22.

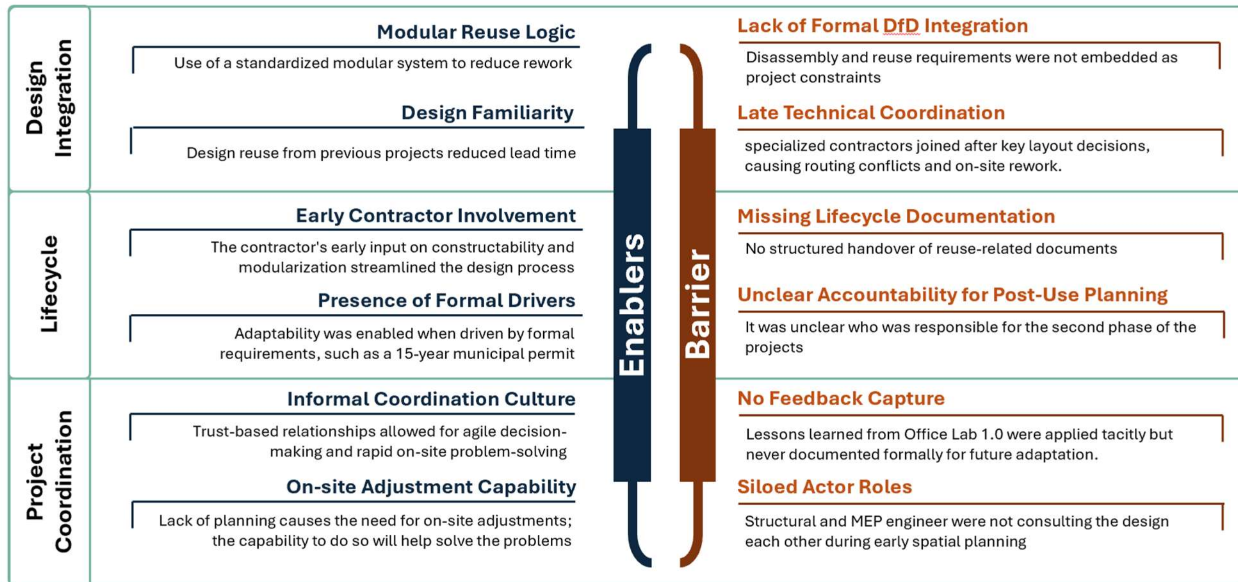


Figure 22 Enablers and Barriers of Implementing Adaptable Building

Enablers

Enablers are defined as the favorable conditions, stakeholder capabilities, and process characteristics that were observed in the case studies to support or facilitate the achievement of adaptability goals actively. These features represent the existing strengths and positive patterns that future frameworks should seek to leverage.

1. Modular Reuse Logic

   The consistent application of standardized modular systems enabled design reusability and minimized rework. The consistent application of a standardized modular system, as seen in both cases, functioned as a key enabler by providing design reusability and minimizing rework. This pre-defined logic provided a clear foundation for planning future modifications.

2. Design Familiarity

   Reusing designs from previous phases reduced lead time and improved predictability. Future frameworks should incorporate knowledge retention tools, for example, design documentation to reinforce continuity across modular building programs, so not rely on the same contractor that built the first phase.

3. Early Contractor Involvement

   Involving contractors during early planning phases showed practical input on constructability and modularization. Constructability reviews by the main contractor or the specialized contractor will validate the design that can be applied in the project site, which will also reduce the feedback loop to the designer or architect in the execution phase. This is crucial for every collaborative delivery model and should be formalized in future projects.

4. Presence of Formal Drivers

   A powerful enabler, observed particularly in Case B, was the presence of a formal, external driver for adaptability. The 15-year municipal permit for the relocatable housing created a non-negotiable, long-term requirement that forced the project team to consider disassembly from the outset. This demonstrates that when adaptability is tied to a clear business case or a contractual/regulatory mandate, it is less likely to be value-engineered out of the project and becomes a core guiding principle for the delivery process

5. Informal Coordination Culture

   While not a formal mechanism, close working relationships enabled quicker alignment and issue resolution. Having a warm collaborative environment will help the team be more open to discussing minor problems without waiting for a formal meeting or correspondence. Future models should recognize the value of embedded teams or co-located environments that enhance informal communication.

6. On-site Adjustment Capability

   The ability to adjust onsite, although reactive, proved vital in resolving late-stage coordination conflicts. This suggests that adaptability should not only be designed-in, but also supported through flexible construction delivery by choosing contractors or builders who have the capabilities to execute adjustments.

Barriers

Barriers are defined as the critical process gaps, structural shortcomings, or organizational disconnects that were found to undermine or constrain a project's adaptability potential. These represent the systemic failures and recurring problems that must be directly addressed and mitigated by a more proper project delivery framework.

1. Lack of Formal DfD Integration

   Disassembly and reuse goals were not encoded in formal specifications or design deliverables. Future delivery frameworks must integrate DfD as a contractual requirement, with traceable outputs and measurable review checkpoints.

2. Late Technical Coordination

   The delayed involvement of technical consultants resulted in rework. This underlines the importance of sequencing and early-stage coordination mapping (for example, via DSM), ensuring dependencies are actively managed.

3. Missing Lifecycle Documentation

   The absence of structured reuse documentation impeded future adaptation. Future-oriented delivery models must establish documentation protocols, such as material passports and BIM-linked O&M datasets, during the design and handover phases.

4. Unclear Accountability for Post-Use Planning

Ambiguity around who owns post-occupancy preparation created fragmentation. Future projects should clearly define lifecycle responsibilities using tools like RACI matrices or long-term performance-based contracts.

5. No Feedback Capture

   Valuable insights from earlier projects were not documented, creating knowledge loss. Future delivery ecosystems should include structured feedback loops (for example, post-use evaluation workshops) to inform design processes continuously.

6. Siloed Actor Roles

   Key specialists (structural and MEP designers) worked in parallel with limited interaction. Integrated design reviews, everyday data environments, and cross-disciplinary coordination loops should be mandatory in future workflows.

Enablers functioned primarily through proper design and collaboration between actors, in contrast, barriers come from missing integration between the project lifecycle, especially when adaptability was not formally integrated into the project scope, design criteria, or governance structure. Taken together, these findings offer a foundational checklist for future framework design. They highlight that adaptability is not solely a modular capability, but a project delivery condition. By integrating early coordination, lifecycle documentation, and modular planning logic into delivery models, future projects can change from reactive to anticipatory strategies for adaptable building.

6

Chapter 6: A Framework for the Development of Adaptable Buildings

Based on the key enablers and barriers identified in the cross-case analysis of Chapter 5, this chapter proposes a refined project delivery framework. The framework is designed to mitigate the identified barriers and leverage the enablers to systematically integrate adaptability into modular construction projects.

6.1 The Refined Framework

Table 15 and Table 16 show a synthesized DSM matrix and RACI matrix that combines insights from DSM analysis, RACI mapping, and observation from both case studies. It visualizes how the modular construction workflow for adaptable buildings can be structured across the delivery phase, with specific dependencies between activities, to make the entire process seamless.

Table 15 Refined DSM Matrix

No.	Activity Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Establish project intent and adaptability goals	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Select delivery method and define responsibilities	2	1		0	0	0	0	0	0	0	0	0	0	0	0	0
3	Appoint key design and execution stakeholders	3	1	0		0	0	0	0	0	0	0	0	0	0	0	0
4	Develop spatial layout and modular configuration	4	1	1	1		0	0	0	0	0	0	0	0	0	0	0
5	Plan structural system and floor/foundation strategy	5	0	0	0	1		1	1	1	1	0	0	0	0	0	0
6	Design building services (MEP)	6	0	0	0	1	1		1	1	1	0	0	0	0	0	0
7	Coordinate layout and modular constraints	7	0	0	0	1	1	1		1	1	0	0	0	0	0	0
8	Integrate disassembly and reuse requirements (DfD)	8	0	0	0	1	1	1	1		1	0	0	0	0	0	0
9	Conduct constructability and feasibility reviews	9	0	0	0	1	0	0	0	1		0	0	0	0	0	0
10	Procure systems, materials, and subcontractors	10	0	0	0	0	0	0	0	0	1		0	0	0	0	0
11	Fabricate modules and prepare off-site logistics	11	0	0	0	0	0	0	0	0	0	1		0	0	0	0
12	Prepare site and foundations	12	0	0	0	0	0	0	0	0	0	0	1		0	0	0
13	Deliver and install modules on site	13	0	0	0	0	0	0	0	0	0	0	1	1		0	0
14	Test systems and perform commissioning	14	0	0	0	0	0	0	0	0	0	0	0	0	1		0
15	Handover documentation and plan post-occupancy support	15	0	0	0	1	0	0	0	1	1	0	1	1	1	1	

Table 16 Refined RACI Matrix

No.	Activity Name	Client	Architect	Contractor	Specialized Subcontractors
1	Establish project intent and adaptability goals	R	C	I	I
2	Select delivery method and define responsibilities	R	C	C	I
3	Appoint key design and execution stakeholders	R	C	C	I

No.	Activity Name	Client	Architect	Contractor	Specialized Subcontractors
4	Develop spatial layout and modular configuration	A	C	R	C
5	Plan structural system and floor/foundation strategy	A	R	C	C
6	Design building services (MEP)	I	C	C	R
7	Coordinate layout and modular constraints	I	C	C	I
8	Integrate disassembly and reuse requirements (DfD)	I	C	R	C
9	Conduct constructability and feasibility reviews	I	C	R	C
10	Procure systems, materials, and subcontractors	I	I	R	C
11	Fabricate modules and prepare off-site logistics	I	I	R	I
12	Prepare site and foundations	I	I	R	C
13	Deliver and install modules on site	I	I	R	I
14	Test systems and perform commissioning	I	I	R	I
15	Handover documentation and plan post-occupancy support	A	C	R	I

Activity Synchronization Across Phases

The delivery flow consolidates fifteen activities into six interconnected domains (planning, design, procurement, fabrication, execution, and handover). The DSM matrix highlights the high-dependency pathways, such as how early planning choices (Activities 1–3) directly shape design integration (Activities 4–9), and how disassembly and documentation efforts (Activities 4, 9, and 15) are either dependent or missed depending on the project's governance.

In this framework, delivery logic is no longer linear but reflexive. Design coordination (Activities 8a–8c) and constructability reviews (Activities 9a–9d) are explicitly staged to act as mid-stream evaluative loops rather than post-design correction. This resolves one of the key barriers identified in both cases, which is late technical involvement.

Integrating Modularity and Lifecycle Adaptability

Activities such as "Integrate disassembly and reuse requirements" (Activity 4) and "Prepare a documentation plan for adaptable purposes" (Activity 9d) are emphasized as central to adaptability. These are supported by modular detailing and feedback-enabled loops that span fabrication and post-occupancy planning (Activity 15). Unlike in Project A (where these steps were isolated), the framework positions them as an embedded coordination hub.

By connecting the modular reuse logic (11a–11c) to both procurement sequencing and early MEP routing strategies (7a, 8c), the framework ensures that construction and adaptation are not contradictory. On the contrary, they become co-optimized through spatial prefiguration.

Actor Coordination and Process Layering

The embedded RACI logic further strengthens this framework. Each clustered activity group is aligned with responsibility distribution lessons, for example, early contractor involvement (2a), design coordination (8a),

and lifecycle continuity (15). These align with roles and gaps observed in the Project A and Project B projects, particularly the need for clear accountability in post-use planning, technical documentation, and disassembly procedures.

The modular diagram highlights the shift from informal, reactive coordination (Project A) to a more layered, cross-disciplinary integration (Project B). Colored arrows and spatial zones illustrate the activity dependencies and the timing of inter-stakeholder handovers, which will enable project teams to visually map risk, role, and resource needs at each phase.

6.2 Core Strategies for Implementation

The strategies present in the Figure 23, are extracted from insights from barriers and enablers from both case studies. This strategy is synthesized based on the main theme, which is design integration, project lifecycle, and coordination between stakeholders.

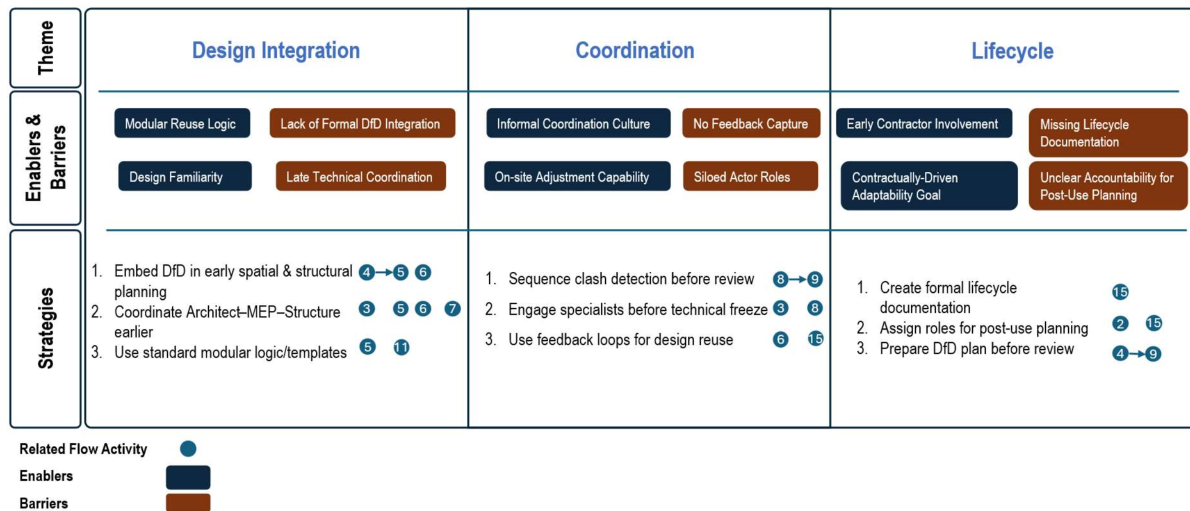


Figure 23 Strategies for Building an Adaptability Project

1. Strategies for Design Integration

Improving design integration is critical to ensuring that modularity and adaptability goals are embedded early and systematically throughout the project lifecycle. Based on the cross-case analysis, several enablers, such as the use of standardized modular logic, design familiarity, and early contractor involvement, support smoother planning and fewer on-site adjustments. However, their effectiveness was often undermined by recurring barriers, particularly the lack of formal DfD integration and late technical coordination.

To address these issues, the following strategic lessons are proposed:

a) Embed DfD in early planning

Disassembly and reuse requirements must be defined in conjunction with the initial design intents. This ensures they are not treated as optional features but as structural constraints influencing layout, connection

types, and component types. DfD principles should inform both the macro (for example, modular zoning) and micro (for example, joint selection) design levels from the outset.

b) Coordinate Architect–MEP–Structure earlier

Many coordination issues stemmed from siloed workflows where structural and MEP engineers were not fully engaged during spatial configuration. A strategic shift toward simultaneous early engagement, particularly in modular construction contexts, is essential to reduce rework and routing clashes.

c) Use standard modular templates

Projects that reused standardized modular systems benefited from reduced lead times and clearer design logic. Standardized templates, such as preferred grid dimensions, interface points, and module types, can help ensure repeatability while still allowing for site-specific customization.

These strategies are intended not as rigid procedural steps but as guiding principles to improve design integration and support more adaptable outcomes across projects.

2. Strategies for Lifecycle

Lifecycle integration refers to the project's ability to anticipate and manage future transitions, such as reuse, relocation, or post-occupancy adaptation, through early planning and structured handover. The case analysis revealed that although lifecycle ambition was present in both project cases, it was inconsistently implemented. Three key barriers stood out: missing lifecycle documentation, unclear accountability for post-use planning, and the absence of feedback capture. Together, these gaps weakened the long-term adaptability potential of modular assets.

To address these limitations, the following strategies are proposed:

a) Create formal lifecycle documentation

Lifecycle objectives, such as intended reuse, future adaptation, or relocation, must be explicitly recorded and translated into deliverables. These may include administration history storage, disassembly protocols, reuse instructions, maintenance plans, or adaptable layout schemes. Documentation should evolve together with the design process and be integrated into project requirements.

b) Assign roles for post-use planning

A recurring issue was the lack of clarity around who was responsible for post-occupancy decisions and support. Without designated ownership, lifecycle tasks such as tracking reuse inventory, coordinating module relocation, or reconfiguring layout often remain undefined and are frequently neglected. Assigning this responsibility (for example, to the client, contractor, or an asset manager) during early project phases enables smoother lifecycle transitions.

c) Prepare DfD plan before reviewing

DfD is often acknowledged in principle but omitted in review workflows. By requiring a preliminary DfD plan to be prepared before key review gates (for example, constructability or technical coordination reviews), teams are forced to operationalize disassembly considerations earlier. This not only supports better reuse but also reduces conflicts later in fabrication and execution.

Together, these strategies help close the gap between design and long-term use and can turn adaptability into a manageable aspect of the project lifecycle.

3. Strategies for Coordination

Coordination strategies aim to align technical specialists, workflows, and decision-making structures across disciplines. The case studies show that while informal coordination practices allow for flexibility, deeper structural gaps still exist. A prominent constraint is the isolated roles of structural and MEP actors, which often result in route conflicts, rework, and design discrepancies. Furthermore, feedback from past projects was seldom captured or reused, thereby reducing organizational learning. To address these challenges and improve coordination quality in modular and adaptable construction, three key strategies are proposed:

a) **Sequence clash detection before review**

In many cases, constructability reviews were conducted before technical coordination was entirely resolved. This sequencing failure led to overlooked spatial conflicts and late-stage redesigns. Embedding clash detection (via BIM or similar tools) prior to formal reviews allows issues to be identified and addressed early. It also enhances the reliability of constructability and lifecycle assessments, particularly in terms of disassembly or reuse logic.

b) Engage specialists before a technical freeze

In both cases, specialist contractors (for example, MEP engineers, structural consultants) were engaged only after key design decisions had been made. This restricted their input and often led to routing issues or constrained module detailing. A revised strategy is to involve these actors earlier so their expertise can shape the layout and detail proactively rather than reactively.

c) Use feedback loops for design reuse

Although some teams relied on previous projects for design templates, there were no formal mechanisms in place to evaluate what worked or failed. By structuring feedback loops (for example, through structured post-occupancy evaluations, reuse audits, or internal design retrospectives), organizations can better reuse not only physical modules but also process knowledge.

These strategies foster a more resilient coordination environment by making key dependencies explicit and embedding adaptive learning within technical workflows.

In summary, enhancing coordination across disciplines is essential for delivering adaptable modular construction projects. The proposed strategies address both technical and organizational shortcomings

identified in the case studies. These measures not only mitigate spatial and sequencing conflicts but also promote iterative learning and smoother design reuse. By improving the timing and quality of interdisciplinary input, these strategies help shift coordination from a reactive, fragmented process to a proactive one. As part of the broader implementation framework, coordination becomes a critical enabler of adaptability that can unlock the potential for scalability.

6.3 The Process Flow for Adaptability

The process flow in Figure 24 presents a structured sequence of interdependent activities tailored to support adaptable modular construction projects. The flow is derived from both DSM analysis and cross-case insights, which emphasize how early design decisions, stakeholder coordination, and lifecycle planning interact to enable long-term adaptability.

The process aligns activities across time and stakeholders, ensuring that adaptability is not an afterthought, but a systemic output of design, delivery, and handover. Feedback loops, multi-actor coordination, and early DfD integration are explicitly structured to enhance the project's capacity for change. For example, activity 8 and 9 become the center of design and execution, which will ensuring all the design will be constructible in the site when executed.

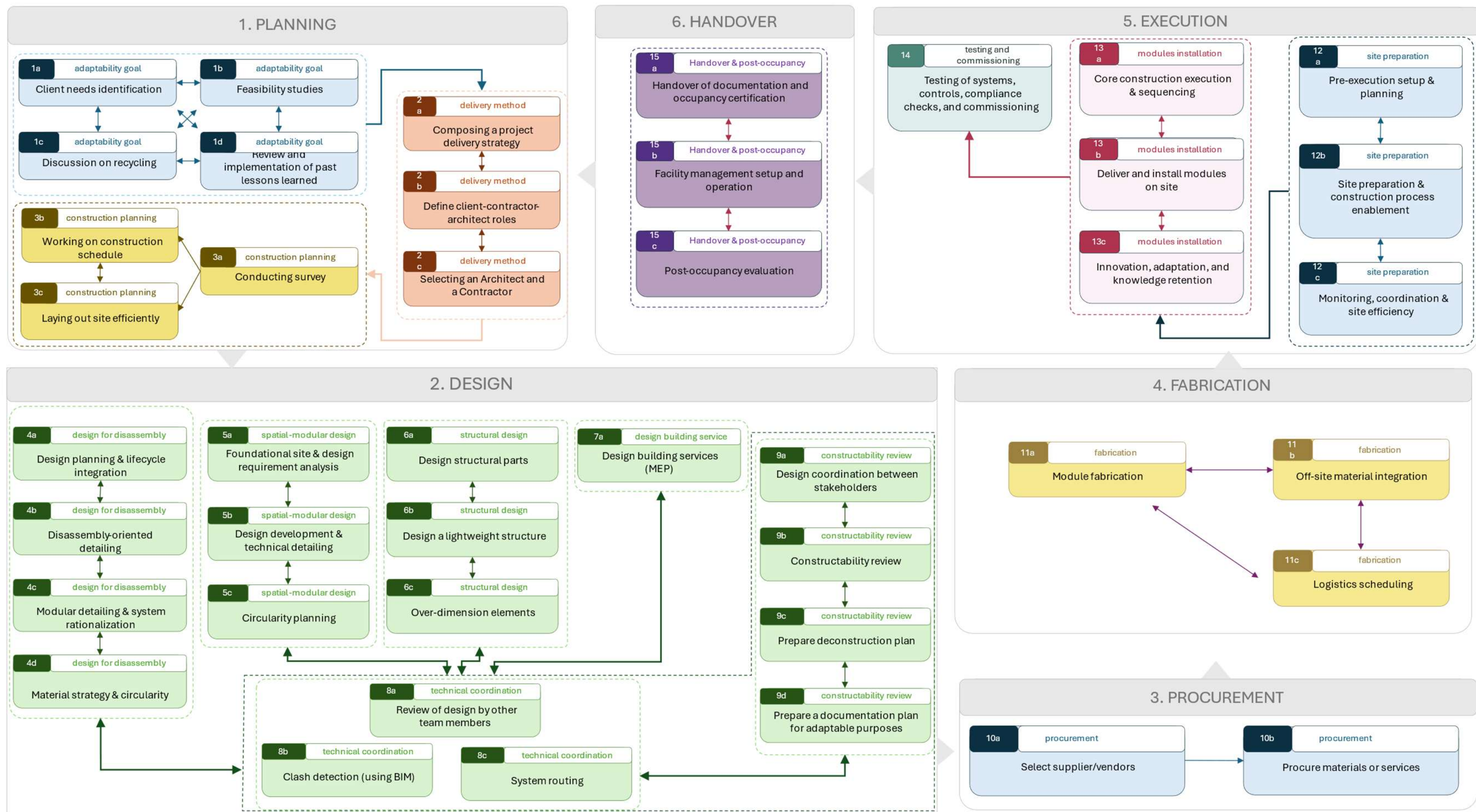


Figure 24 Process Flow of Adaptability Building Project

6.4 Conclusion

This chapter synthesizes findings from two case studies of modular construction to explore how project delivery models influence the implementation of adaptable buildings. Through DSM and RACI analysis from the previous chapter, it was shown that while adaptability is often a project ambition, it rarely translates into structured activity flows or assigned responsibilities. For example, the Project A illustrated the risk of informal coordination and undocumented reuse, which may fall short in lifecycle continuity if responsibilities remain ambiguous.

The resulting framework reorders activity dependencies, clarifies actor roles, and adds a feedback mechanism across the project lifecycle. It will help to structure the strategies to guide adaptable construction workflows in future projects. Chapter 6 will translate these insights into practical recommendations for project stakeholders on how to apply the framework in real-world project settings. The recommendations aim to ensure that adaptability is no longer treated as an afterthought but is integrated from the start through project delivery structuring.

7

Chapter 7: Discussion

The analysis presented in the preceding chapters reveals a clear and compelling conclusion: the successful delivery of an adaptable building is not merely a technical achievement but a socio-technical one. While the physical design, modular logic, and material selection form the essential technical system that enables change, this research demonstrates that these elements are insufficient on their own. Their potential is often wasted if not supported by a coherent process system (as mapped by the DSM) and a social system that defines stakeholder roles and responsibilities (as analyzed through the RACI matrix). The failures observed in both case studies were not rooted in a lack of technical capability, but rather in the misalignment between these critical systems.

While this research focuses on the context of adaptable construction, the core findings speak to a more universal challenge: the management of complex systems under long-term uncertainty. The observed 'socio-technical misalignment' is not unique to the building industry but is a common failure mode in fields ranging from software development to public policy, where static project delivery models are often misapplied to dynamic, evolving problems.

The purpose of this chapter is to explore the broader implications of this core finding. It will begin by connecting this socio-technical perspective back to the existing literature, notably the "Vicious Circle of Blame," to offer a new, process-based understanding of this persistent industry challenge. The discussion will then delve into the nuanced role of modularity and highlight how delivery gaps can undermine its technical benefits. Following this, the chapter will translate these insights into practical implications for industry stakeholders. Finally, to ensure academic accuracy, the limitations of this study will be acknowledged, and recommendations for future research will be proposed to build upon the findings presented here.

7.1 The Socio-Technical Nature of Adaptability

As introduced in the literature review, the findings of this research can be effectively interpreted through the socio-technical lens of Leavitt's Diamond (Leavitt, 1965) as can be seen in Figure 25. The persistent misalignment between technical capability and delivery execution observed in the case studies represents a classic failure to align the four core variables of the project system.

In the context of this research, the Technology component is represented by the advanced modular systems and DfD principles. The Tasks are the 15 core delivery activities required for the project. The Structure is defined by the Project Delivery Method and the process workflows mapped by the DSM. Finally,

the People are the project stakeholders, whose roles and responsibilities were analyzed using the RACI matrix.

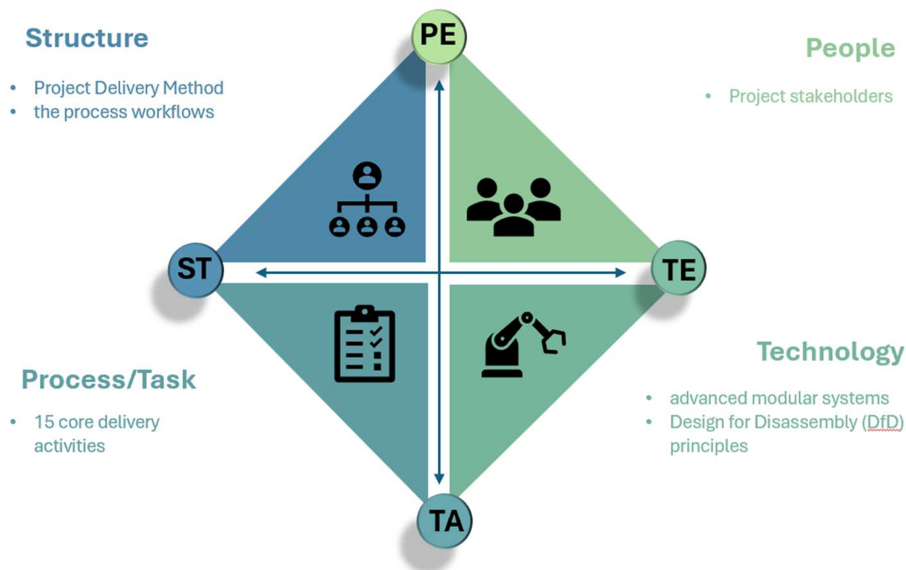


Figure 25 Leavitt's Diamond Diagram

Both case studies demonstrate a classic socio-technical failure. They introduced an innovative Technology (modularity for adaptability) without sufficiently realigning the Structure (the PDM and workflows) and the People (clear roles and lifecycle accountability). In Case A, the informal Structure and siloed People were not robust enough to support the Tasks required for long-term adaptability. In Case B, while the Structure was more integrated, a critical misalignment between the Technology (a reusable building on a permanent foundation) and the ultimate Task (relocation) created a fatal flaw. This confirms that successful adaptability is not just a technological challenge but an organizational design problem. The framework proposed in this thesis is therefore a direct attempt to create this socio-technical alignment, ensuring that the project's structure and roles are designed to fully support the tasks required by an adaptable technology.

7.2 Revisiting the "Vicious Circle of Blame"

In the initial literature review, this thesis introduced the "Vicious Circle of Blame" (Hartenberger, 2008) a concept that describes the cyclical finger-pointing among clients, designers, and contractors that hinders innovation in sustainable construction. This phenomenon, where each party claims the other is responsible for the lack of progress, has long been understood as a problem of mindset, incentives, and risk aversion. However, the findings from this research suggest that this vicious circle is not only a behavioral issue, but it is actively constructed and reinforced by the very project delivery processes that govern the industry.

The analysis of Case A and Case B provides compelling evidence in support of this process-based perspective. The fragmented and linear workflow observed in Case A, as visualized by its DSM, creates a system where accountability for long-term goals is naturally diffused. When design disciplines operate in silos and constructability reviews lack iterative feedback loops, no single actor feels ownership over the final, integrated outcome. This process structure creates the perfect conditions for blame to circulate. The designer

can blame the contractor for poor execution, while the contractor can fault the designer for an unbuildable plan, and the client is left with a building that fails to meet its adaptability goals.

Therefore, this research posits that breaking the Vicious Circle of Blame requires more than just fostering a collaborative mindset. It demands a fundamental redesign of the underlying project delivery process. The framework proposed in Chapter 6, with its emphasis on integrated feedback loops, early cross-disciplinary involvement, and formally assigned lifecycle responsibilities, is not just a tool for improving efficiency. It is a direct intervention designed to close the procedural gaps that allows the Vicious Circle of Blame to persist. By embedding clear and shared accountability into the workflow itself, the delivery model can shift from a structure that facilitates blame to one that mandates collaboration.

7.3 Modularity: Technical Capability vs. Delivery Gaps

A central feature of both case studies was the use of modular construction, a method widely promoted as a key technical enabler for building adaptability. The ability to prefabricate components off-site and assemble them with standardized connections theoretically makes future disassembly, reconfiguration, and reuse far more feasible than in traditional construction. The findings of this research confirm that modularity is indeed a powerful tool that provides the essential technical capability for a building to be physically adapted.

However, the analysis also reveals another potential drawback: the technical potential of a modular system is easily compromised by gaps in the project delivery model. This was most illustrated in Case B. Here, a reusable modular superstructure was placed on a permanent and non-reusable foundation. This created a fundamental contradiction where the building was simultaneously adaptable and fixed. The delivery process had treated the building and its foundation as separate problems and had failed to integrate them into a single, long-term, relocatable structure.

Similarly, in Case A, the modular system provided the physical means for horizontal expansion, which was executed efficiently. However, the initial ambition for vertical expansion was rendered impossible by a foundation that was not designed to support it. Furthermore, the lack of as-built documentation for the modified modules and MEP systems effectively transformed a technically adaptable system into a non-seamless process that makes future modifications more difficult.

These cases reveal a crucial lesson that modularity, on its own, does not guarantee adaptability. It only provides the potential. Realizing this potential is entirely dependent on a project delivery model that is holistically aligned with the long-term adaptability goal. This includes ensuring that all interconnected systems are part of the adaptability plan, and that the documentation, handover plans, and lifecycle governance are as robust as the infrastructure of the physical modules themselves. Without this comprehensive delivery framework, even the most advanced modular system risks becoming a fixed asset with unfulfilled promises.

7.4 Evaluation of Developed Framework

The framework developed in Chapter 6 provides a concrete method for overcoming the systemic failures observed in case studies. Its value for practitioners lies in its intentional realignment of three core elements: activity sequencing, actor responsibility, and lifecycle continuity.

First, the framework's logic of activity sequencing is a direct response to the coordination breakdowns that hinder adaptability. Rather than adhering to conventional linear stages, it reorganizes the project workflow

based on functional influence. For instance, DfD is positioned as an early-stage input to ensure it shapes decisions on layout, procurement, and technical detailing, not as a late-stage consideration. Similarly, by clustering and front-loading technical coordination activities, the framework mitigates the clashes between structure, systems, and modules that were prominent in both cases. This structure transforms the delivery logic from reactive problem-solving to proactive, integrated planning.

Second, the framework addresses the critical issue of ambiguous ownership through explicit mapping of actors and activities. A primary finding from the case studies was that critical tasks failed because they lacked a designated owner. The proposed RACI matrix resolves this by assigning clear responsibilities to the client, architect, and contractor across the entire lifecycle. This ensures that adaptability becomes a shared and contractual responsibility rather than an informal hope. It strategically positions technical consultants and contractors as active co-designers of long-term flexibility, moving them from passive executors to vital contributors in the early design phases.

Finally, the framework systematically bridges the gap between a building's first and second lifecycles. In current practice, the transition from initial use to future reuse is often an afterthought and relies on tacit knowledge that is lost over time. The framework introduces formal closure mechanisms, such as mandatory post-use planning and documentation (Activity 15), which link the project's delivery to its future potential. By assigning clear accountability for creating reuse plans and documenting modular logic, the framework ensures that adaptability is not just a theoretical design feature but an operational option for the building's future.

The existing literature strongly supports this empirically grounded approach. The call for early actor alignment resonates with the work of (Engebø et al., 2020), while the integration of DfD principles is supported by studies from Durmisevic (2019) and Akinade et al. (2017). Methodologically, the use of the DSM proved very important. As both a diagnostic and design tool, DSM was essential for visualizing hidden dependencies and structuring a more iterative workflow. It provided the analytical backbone for developing a framework that embeds adaptability into the core of the project delivery process.

7.5 Implications for Project Delivery Practice

The findings of this research, synthesized in the socio-technical framework in Chapter 6, carry significant practical implications for the construction industry. They call for a shift away from traditional, fragmented delivery models toward more integrated and lifecycle-aware approaches. The lessons learned from the case studies offer specific guidance for key stakeholders, as can be seen in Figure 26, seeking to deliver adaptable buildings successfully.

Figure 26 Practical implications for stakeholders

1. For Clients and Developers

The findings from this research carry a critical implication for clients and developers: to be successful, adaptability must be elevated from a vague ambition to a core contractual requirement. As Case A demonstrated, informal goals are easily compromised during project execution, resulting in lost long-term value. To prevent this, clients must add the lifecycle vision by embedding it into their procurement and project management strategies. Crucially, this vision must also extend into their ongoing Operations & Maintenance (O&M) practices, ensuring that the knowledge and documentation delivered at handover are actively used and maintained throughout the building's lifecycle. This begins with specifying adaptability as a key deliverable in the project brief and scope of work, where the intended future use (be it expansion, relocation, or reconfiguration) is explicitly defined.

Furthermore, clients must mandate the delivery of comprehensive lifecycle documentation as a non-negotiable condition of final project acceptance. This means contracts should require not only the physical asset but also the critical information needed to manage its future, such as DfD plans, material passports, and detailed as-built drawings. Finally, clients should adjust their procurement strategies to prioritize collaboration. This involves selecting project teams based not just on the lowest cost, but on their ability to work in a collaborative environment, potentially delivery models like IPD or a well-structured D&B that contractually incentivize early and continuous stakeholder collaboration.

2. For Project Managers and Contractors

As the primary integrators of the project delivery process, project managers and contractors must change from being executors of a pre-defined plan to becoming proactive members of early system integration. The challenges observed in the case studies, particularly the costly rework stemming from late coordination. To achieve this, project leaders should be able to use early and cross-disciplinary workshops. Rather than waiting for design clashes to emerge reactively in BIM models, they should mandate collaborative sessions where architects, structural engineers, and MEP specialists co-design the initial layout and system zoning together and then resolve potential conflicts before they become embedded in the design.

Furthermore, project managers and contractors should utilize proactive planning tools to structure this collaboration. Frameworks like the DSM and the RACI matrix should not be confined to academic analysis, but instead adopted as practical instruments at the project. These tools can be used to map critical dependencies and clarify stakeholder responsibilities before they become points of conflict, creating a shared understanding of the project workflow. Finally, the contractor's role must extend beyond physical completion to overseeing a formal lifecycle handover. This means taking responsibility for compiling and transferring all required lifecycle documentation, thereby bridging the critical gap between the construction phase and the building's long-term operational life and ensuring its future adaptability is secure.

3. For Designers and Architects

The findings of this research call for architects and engineers to expand their role beyond aesthetics and initial function to become systems integrators, designing the entire building lifecycle. This requires a fundamental shift towards designing the system, not just the object. As highlighted by the failure in Case B, where a reusable superstructure was placed on a permanent foundation, designers must consider the building's critical interfaces (between modules, with the site, and among building systems) as integral parts of the adaptability strategy from the very beginning.

Furthermore, DfD must be embraced as a primary driver of technical design, not an afterthought. DfD principles should inform the earliest design decisions, influencing everything from the modular grid and connection details to material selection and the long-term accessibility of MEP components. Finally, the design process itself must embrace iteration. To deliver buildings that are both constructible and flexible, designers must be open to and actively seek feedback from contractors and specialists throughout the project, using this input to continually refine and improve the design.

By adopting these respective practices, industry stakeholders can collectively begin to close the gap between adaptability ambition and delivery reality. This requires establishing robust systems for knowledge management, where lessons learned are formally documented and fed into a continuous improvement loop to prevent repetition of errors. The most important thing, transforming adaptability from a niche concept into a value-driven outcome, is not the responsibility of a single actor, but a shared commitment to a more integrated and proactive project delivery culture.

4. For Facility Managers and Circular Consultants

The inclusion of a formal post-use planning activity offers a clear handover point for lifecycle continuity. Facility managers, who are typically excluded from early design phases, are brought in as future-facing actors responsible for managing adaptability beyond handover. This encourages clients to institutionalize reuse logic and documentation during construction, not after.

5. For Policymakers and Industry Bodies

This framework may also inform procurement criteria, project guidelines, or circular construction standards. By translating adaptability into structured responsibilities and decision points, the framework could support public and private actors incentivizing or mandating lifecycle-based planning, especially for publicly funded modular developments.

Beyond the construction industry, the principles of this socio-technical framework have broader implications. The challenge of aligning a flexible technology with a rigid delivery process is common in many other sectors. In software development, for instance, agile methodologies were created to solve the exact problem of static waterfall processes failing to deliver dynamic software. Similarly, in healthcare, designing a hospital building for future changes in medical technology and patient care models requires the same holistic integration of the physical structure, the operational workflows, and the roles of clinical staff. In aerospace, designing a modular satellite platform for future upgrades in orbit presents a parallel challenge. The core lesson is universal: The value of any adaptable technology depends on adaptable governance and delivery systems..

7.6 Limitations of the Study

To ensure academic accuracy, it is essential to acknowledge the limitations of this research, which define the boundaries of its findings and provide context for their interpretation. While this study offers in-depth insights into the delivery of adaptable buildings, its conclusions should be considered considering the following limitations:

- Limited sample size: The research is based on an in-depth, qualitative analysis of two case studies. While this approach provides detailed insights, the findings may not be statistically generalizable to the entire construction industry. The specific challenges and enablers identified are deeply rooted in the context of these two projects.
- Context-specific focus: Both case studies were located in the Netherlands and involved modular and off-site construction methods. The findings are therefore most directly applicable to projects within this geographical and technical context. The dynamics of delivering adaptable buildings using traditional on-site construction methods or in different regulatory environments may vary.
- Perspective of interviewee: The data was primarily collected through interviews with mid-level project professionals, such as project managers, technical designers, and site engineers. While these individuals provided ground-level perspectives on the delivery process, the study had limited input from high-level strategic actors, such as public-sector clients, developers, or regulatory bodies. A broader range of stakeholder perspectives could have revealed additional insights into the institutional and financial barriers to adaptable construction.

These limitations do not invalidate the findings but rather frame them as a detailed snapshot of specific real-world practices. They also serve as a foundation for identifying valuable avenues for future inquiry.

8

Chapter 8: Conclusion

8.1 Introduction

This thesis was initiated to address a critical challenge within the construction industry: the gap between the growing need for adaptable buildings and the inadequacy of PDMs to support this objective. While the benefits of adaptability (such as extended building lifespan, reduced waste, and extended long-term value) are widely acknowledged, project delivery practices often remain focused on short-term metrics and fail to integrate lifecycle considerations. This research has explored how PDMs can be restructured to bridge this gap, with a specific focus on modular construction as a key technical enabler.

The purpose of this final chapter is to present the conclusions of this study. It will do so by systematically answering the main research question and the four sub-questions that have guided this investigation from the outset. By synthesizing the insights gathered from the literature review, the in-depth analysis of two Dutch case studies, and the subsequent development of a delivery framework, this chapter provides a comprehensive answer to how project delivery can be better structured to ensure adaptability is not just an ambition, but an achievable outcome. For this research objective, the following research question was formulated.

"How can project delivery be structured to better support building adaptability in modular construction projects?"

To answer the main question, the following sub-questions are formulated, which are answered in the following sections

8.2 Answering the Sub-Questions

8.2.1 Influential Activities and Decisions (Answering SQ1)

SQ1: "What delivery activities and decisions influence a building's capacity to support adaptability over time?"

The first sub-question aimed to identify which delivery activities and decisions have the most significant influence on a building's capacity for adaptability over time. The findings of this research conclude that the most influential activities are not those related to the execution of the modular system itself, but rather those that occur at the very beginning and very end of the project lifecycle: early-stage strategic and late-stage lifecycle planning.

The case study analysis revealed that a few key decisions have a significant impact on long-term adaptability. Critically, the design of the foundation and its integration with the superstructure proved to be a primary determinant of a building's future potential. As seen in both cases, a failure to engineer the foundation for future change (for example, vertical expansion in Case A or relocation in Case B) rendered even the most sophisticated adaptable superstructures effectively fixed.

Equally influential was the decision to formally integrate DfD principles into the contractual scope of work. When DfD was treated as an informal ambition rather than a required deliverable, it was easily ignored, which led to uncoordinated designs and a loss of potential reuse value. Finally, the creation and structured handover of comprehensive lifecycle documentation emerged as a critical activity. Without as-built drawings, material passports, or disassembly guides, the "know-how" of the building's adaptability is lost, making future modifications risky and expensive.

Conversely, the research consistently found that reactive and late-stage decisions consistently undermine adaptability. Adjustments made on-site to resolve unforeseen clashes, while necessary for short-term project completion, often result in undocumented changes that compromise the planned flexibility of the system. Therefore, the capacity for adaptability is determined less by the technical modular system and more by the foresight embedded in early-stage decisions and the rigor of the project's handover and documentation processes.

8.2.2 Stakeholder Interactions and Roles (Answering SQ2)

SQ2: "How do stakeholders interact during the project lifecycle to support adaptability?"

The second sub-question explored how stakeholders interact during the project lifecycle to support adaptability. This research concludes that the nature of stakeholder interaction is a critical factor, and that the two case studies presented two distinct models of coordination.

In Case A, stakeholder interaction was governed mainly by informal, relationship-based coordination. This approach, built on pre-existing trust and familiarity, provided short-term agility, which allows the team to solve problems reactively. However, it led to a significant lack of formal accountability. As the RACI analysis revealed, responsibilities for long-term adaptability were scattered and undocumented, resulting in a fragile system that was dependent on the knowledge of specific individuals.

In contrast, Case B utilized a formally hierarchical interaction model, with a single turnkey contractor managing all downstream communication. This created clear lines of authority and resulted in a highly efficient and predictable execution process. However, this rigid structure led to siloed communication and limited the early and innovative input from key specialists like the architect and structural engineer, whose roles became more consultative than collaborative. This resulted in critical oversights, such as the non-adaptable foundation, which were not caught because the right stakeholders were not empowered to interact on a systemic level.

Therefore, this research concludes that to effectively support adaptability, stakeholder interaction must follow a hybrid model. Such a model must combine the collaborative communication and trust of an informal approach with the clear roles and responsibilities of a formal structure. This is best achieved through mandatory, early cross-disciplinary workshops where all key stakeholders co-design the project's foundational concepts, which are supported by a clear RACI matrix that formally assigns ownership for critical

lifecycle and integration tasks. This ensures that both flexibility and accountability are built into the interaction process from the start.

8.2.3 Similarities and Differences Across Cases (Answering SQ3)

SQ3: "How do the observed similarities and differences in project delivery structures and coordination processes between the case studies influence their respective capacities to deliver long-term building adaptability?"

The third sub-question inquired about how the observed similarities and differences in the project delivery structures of the case studies impacted their capacity to deliver long-term adaptability. The comparative analysis revealed insightful patterns that highlight the systemic nature of this challenge.

The most significant similarity between Case A and Case B was their shared failure to formalize and operationalize lifecycle planning. Despite having different delivery models, motivations, and levels of integration, both projects left long-term adaptability at significant risk. Case A's informal ambition for future expansion was never translated into a structured plan, while Case B's clear relocation goal lacked the post-use accountability. This common gap underscores a critical finding: regardless of the chosen PDM, adaptability will remain a fragile concept unless it is supported by explicit contractual deliverables, reliable documentation, and assigned ownership for the building's entire lifecycle.

The key difference between the two cases lies in their coordination models and integration approaches. Case A's delivery was fragmented and relationship-driven, characterized by a linear workflow and late engagement of specialists. This created horizontal silos that led directly to on-site rework and compromised the building's technical adaptability. In contrast, Case B's contractor-led D&B model was highly integrated and efficient, avoiding these horizontal silos. However, its rigid, hierarchical structure created a vertical silo.

In conclusion, the comparison demonstrates that neither a purely informal, fragmented model nor a rigidly integrated, hierarchical model is sufficient to deliver holistic, long-term adaptability. Case A's agility came at the expense of accountability, while Case B's efficiency came at the expense of systemic and holistic integration. This highlights the need for a hybrid delivery model that balances structure with collaboration, which will ensure that all critical systems and lifecycle phases are integrated under a unified strategy for adaptability.

8.3 Structuring Project Delivery for Adaptability (Answering the Main Research Question)

Main Research Question: "How can project delivery be structured to better support building adaptability in modular construction projects?"

The main research question of this thesis asked how project delivery can be structured to better support building adaptability in modular construction projects. The comprehensive answer, derived from the synthesis of the literature review and the cross-case analysis, is that project delivery must be structured as a holistic socio-technical system. The findings demonstrate that adaptability is not a product of technical design alone but is an emergent property that arises from the alignment of a project's technical systems, actor collaboration, and process workflows. To achieve this alignment, a project delivery structure must be built upon three core elements, which are operationalized in the framework developed in this thesis.

First, it requires a process-oriented structure that is iterative, not linear. As shown in the refined DSM, the workflow must be reorganized to front-load critical adaptability-focused activities, such as DfD planning. Furthermore, the process must embed reflexive feedback loops that connect construction and post-occupancy phases back to early design, which allows for continuous refinement and learning rather than reactive problem-solving.

Second, this process must be supported by a clearly defined social structure with explicit accountability. The RACI matrix developed in the framework addresses this by assigning clear ownership for critical lifecycle outcomes. This moves beyond simply defining roles to establishing who is ultimately Accountable for deliverables like DfD documentation and post-use planning. This formal social structure ensures that long-term goals are not lost in the transition between project phases or stakeholder teams.

Finally, the delivery structure must enforce a system-wide technical scope. The failures in both cases stemmed from a narrow integration scope that focused only on the modular superstructure. An effective structure must ensure that the integration plan is holistic, encompassing all critical components (including the substructure, site interfaces, and MEP systems) under a single and unified adaptability goal. By integrating these three elements, the project delivery method itself becomes the primary mechanism for transforming adaptability from an informal ambition into a robust, manageable, and ultimately deliverable outcome.

8.4 Contributions of Research

This thesis offers several contributions to both academic theory and construction industry practice by providing a new, evidence-based perspective on delivering adaptable buildings.

Contribution to Theory

The primary theoretical contribution of this research is the development of a socio-technical framework for analyzing and structuring project delivery for adaptability. While prior studies have often focused on either the technical aspects of adaptable design or the behavioral dynamics of stakeholders, this thesis integrates these dimensions. It contributes to the academic discourse in some key ways:

1. Provides a process-based explanation for the "Vicious Circle of Blame," (Hartenberger, 2008) demonstrating how fragmented delivery workflows and a lack of formal accountability create the systemic conditions for this phenomenon to persist.
2. Introduces a combined application of the DSM and the RACI matrix as a methodological approach to simultaneously diagnose and prescribe improvements for the process and social systems of a project.
3. Extends the literature on modular construction by showing that its technical benefits are contingent upon a holistically aligned delivery model, thereby shifting the focus from the "what" of modularity to the "how" of its delivery.
4. Confirms that early-stage alignment is crucial (as noted by (Engebø et al., 2020), but adds nuance by showing which activities must occur early and how they interdependently shape downstream adaptability.

Contribution to Practice

For industry professionals, this research provides a tangible and actionable framework to move beyond the common pitfalls of delivering adaptable buildings. The practical contributions include:

1. A Structured Roadmap for Project Delivery: The refined 15-activity workflow, DSM, and RACI matrix offer project managers, clients, and contractors a clear, step-by-step guide for structuring their projects to mitigate risks and ensure long-term goals are met.
2. Actionable Strategies for Key Stakeholders: The research provides specific, targeted strategies for clients, designers, and contractors to improve design integration, formalize lifecycle planning, and enhance coordination.
3. A Communication and Planning Tool: The framework itself can be used as a practical tool at the project outset to align stakeholder expectations, clarify roles, and proactively map the critical dependencies necessary for success.

This thesis presents a model for how organizations can move beyond creating adaptable products to building adaptable processes. By demonstrating the need to counteract the optimism bias through formalized lifecycle planning and aligning technical, process, and social systems, this research offers insights relevant not only to the construction industry but also to any organization seeking to design for resilience in a changing world.

8.5 Recommendations for Future Research

The insights and limitations of this thesis open up several possibilities for future research that could build upon its conclusions, especially in terms of understanding how to deliver adaptable buildings. The following areas are recommended for further investigation:

1. Cost Analysis

While this study focused on the qualitative aspects of project delivery, quantitative research is needed to assess the economic implications of the proposed framework. Future studies could analyze the return on investment (ROI) of implementing formal lifecycle planning and DfD documentation, comparing the upfront costs with the long-term value generated through easier adaptation and reuse.

2. Expansion to Diverse Project Types

Future research should apply a similar socio-technical analysis to a wider range of projects to enhance the generalizability of the findings. This could include case studies of adaptable buildings constructed using traditional on-site methods, projects operating under different contractual models (such as Integrated Project Delivery, or IPD), and buildings in various market sectors (e.g., commercial retail, healthcare).

3. Longitudinal Case Studies

This research provided a cross-sectional view of projects during or shortly after delivery. A longitudinal study that follows an adaptable building project from its initial conception through its first major reconfiguration or relocation would be invaluable. Such research could track how the delivery decisions and documentation (or lack thereof) directly impact the real-world cost, time, and success of future adaptations.

4. Development of Digital Tools

This study highlights the disconnection between process mapping (DSM), role assignment (RACI), and technical design (BIM). Future research could focus on developing and testing integrated digital platforms that combine these tools. Such a platform could enable project teams to proactively model and manage the socio-technical alignment of their projects in a shared data environment, which will make the principles of the proposed framework more accessible and easier to implement.

5. Exploring Procurement and Contractual Implications

Future work should also examine how procurement models and contractual arrangements influence the adoption of adaptability strategies. Topics such as early contractor involvement (ECI), performance-based contracts, and lifecycle incentives could be explored to understand better the conditions under which this framework can be embedded into mainstream project delivery.

References

Addis, W., & Schouten, J. (2004). *Principles of design to faciliate reuse and recycling*. CIRIA.

Ahmed, S., & El-Sayegh, S. (2020). Critical Review of the Evolution of Project Delivery Methods in the Construction Industry. *Buildings*, *11*(1), 11. https://doi.org/10.3390/buildings11010011

Al Khalil, M. I. (2002). Selecting the appropriate project delivery method using AHP. *International Journal of Project Management*, *20*(6), 469–474. https://doi.org/10.1016/S0263-7863(01)00032-1

Alleman, D., Antoine, A., Papajohn, D., & Molenaar, K. (2017). Desired Versus Realized Benefits Of Alternative Contracting Methods On Extreme Value Highway Projects. *Proceedings of International Structural Engineering and Construction*, *4*(1). https://doi.org/10.14455/ISEC.res.2017.34

Askar, R., Bragança, L., & Gervásio, H. (2021). *Adaptability of Buildings: A Critical Review on the Concept Evolution*.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. In *Qualitative Research in Psychology* (2nd ed., Vol. 3, pp. 77–101). https://doi.org/10.1191/1478088706qp063oa

Chen, Y. Q., Liu, J. Y., Li, B., & Lin, B. (2011). Project delivery system selection of construction projects in China. *Expert Systems with Applications*, *38*(5), 5456–5462. https://doi.org/10.1016/j.eswa.2010.10.008

Davies, A., MacAulay, S. C., & Brady, T. (2019). Delivery Model Innovation: Insights From Infrastructure Projects. *Project Management Journal*, *50*(2), 119–127. https://doi.org/10.1177/8756972819831145

Durmisevic, E., & Brouwer, J. (2022). Design Aspects of Decomposable Building Structures. *Inhouse Publishing: Rotterdam*.

Engebø, A., Lædre, O., Young, B., Larssen, P. F., Lohne, J., & Klakegg, O. J. (2020). Collaborative Project Delivery Methods: A Scoping Review. *Journal of Civil Engineering and Management*, *26*(3), 278–303. https://doi.org/10.3846/jcem.2020.12186

Forbes, L. H., & Ahmed, S. M. (2010). *Modern construction: Lean project delivery and integrated practices.* CRC press. https://doi.org/10.1201/b10260

Geraedts, R. P., & van der Voordt, T. J. (2014). Developing a tool to measure building adaptability. *Facilities*, *32(9/10)*, 548-56932(9/10).

Gioia, D. (2021). A systematic methodology for doing qualitative research. *The Journal of Applied Behavioral Science*, *57(1)*, 20-29. https://doi.org/10.1177/0021886320982715

Gosling, J., Sassi, P., Naim, M., & Lark, R. (2013). Adaptable buildings: A systems approach. *Sustainable Cities and Society*, *7*, 44–51. https://doi.org/10.1016/j.scs.2012.11.002

Groot, J. (2022). Flexwoningen als aanvulling op het woningaanbod. *Planbureau voor de Leefomgeving*.

Haberfellner, R., & De Weck, O. (2005). 10.1.3 Agile System Engineering versus Agile System engineering. *INCOSE International Symposium*, *15*(1), 1449–1465. https://doi.org/10.1002/j.2334-5837.2005.tb00762.x

Hartenberger, U. (2008). *Breaking the Vicious Circle of Blame: Making the Business Case for Sustainable Buildings, Findings in Built and Rural Environments*. Royal Institution of Chartered Surveyors.

Khan, S. (2016). Application of Design Structure Matrix (DSM) for Managing Projects on the Basis of Constructability. *Civil Engineering and Architecture*, *4*(3), 91–111. https://doi.org/10.13189/cea.2016.040302

Lædre, O., Austeng, K., Haugen, T. I., & Klakegg, O. J. (2006). Procurement Routes in Public Building and Construction Projects. *Journal of Construction Engineering and Management*, *132*(7), 689–696. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:7(689)

Leaman, A., Bordass, B., & Cassels, S. (1998). *Flexibility and Adaptability in Buildings: The "killer" variables*.

Leavitt, H. J. (1965). *Applied Organizational Change in Industry: Structural, Technical and Humanistic Approaches*.

Lee, W., Lee, S., Jin, C., & Hyun, C. (2021). Development of the RACI Model for Processes of the Closure Phase in Construction Programs. *Sustainability*, *13*(4), 1806. https://doi.org/10.3390/su13041806

Lu, W., Tan, T., Xu, J., Wang, J., Chen, K., Gao, S., & Xue, F. (2021). Design for manufacture and assembly (DfMA) in construction: The old and the new. *Architectural Engineering and Design Management*, *17*(1–2), 77–91. https://doi.org/10.1080/17452007.2020.1768505

Mafakheri, F., Dai, L., Slezak, D., & Nasiri, F. (2007). Project Delivery System Selection under Uncertainty: Multicriteria Multilevel Decision Aid Model. *Journal of Management in Engineering*, *23*(4), 200–206. https://doi.org/10.1061/(ASCE)0742-597X(2007)23:4(200)

Mahdi, I. M., & Alreshaid, K. (2005). Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP). *International Journal of Project Management*, *23*(7), 564–572. https://doi.org/10.1016/j.ijproman.2005.05.007

Manewa, A., Siriwardena, M., Ross, A., & Madanayake, U. (2016). Adaptable buildings for sustainable built environment. *Built Environment Project and Asset Management*, *6*(2), 139–158. https://doi.org/10.1108/BEPAM-10-2014-0053

Mlote, D. S., & Budig, M. (2022). Load-Bearing Capacities and Pseudo-Ductility of Carbon Fiber-Reinforced New Zealand Pine Timber Beams. *Journal of Composites Science*, *6*(8), 239. https://doi.org/10.3390/jcs6080239

Mlote, D. S., Budig, M., & Cheah, L. (2024). Adaptability of buildings: A systematic review of current research. *Frontiers in Built Environment*, *10*, 1376759. https://doi.org/10.3389/fbuil.2024.1376759

Ostapska, K., Rüther, P., Loli, A., & Gradeci, K. (2024). Design for Disassembly: A systematic scoping review and analysis of built structures Designed for Disassembly. *Sustainable Production and Consumption*, *48*, 377–395. https://doi.org/10.1016/j.spc.2024.05.014

Pinder, J., Iii, R. S., & Saker, J. (2013). Stakeholder perspectives on developing more adaptable buildings. *Construction Management and Economics*, *31*(5), 440–459. https://doi.org/10.1080/01446193.2013.798007

Project Management Institute. (2017). *A Guide to the Project Management Body of Knowledge (PMBOK® Guide) (6th ed.)*. Project Management Institute.

Ross, B. E., Chen, D. A., Conejos, S., & Khademi, A. (2016). Enabling adaptable buildings: Results of a preliminary expert survey. *Procedia Eng*. https://doi.org/doi: 10.1016/j.proeng.2016.04.009

Septiyanto, A., Wulansari, K., & Zuhaida, A. (2023). Varieties of qualitative research methods selected contextual perspectives: Edited by J. M. Okoko, S. Tunison, and K. D. Walker, Cham, Switzerland, Springer Nature, 2023, XVII+495 pp., €59,99 (hardback), ISBN 9783031043963. *The Social Science Journal*, 1–2. https://doi.org/10.1080/03623319.2023.2243681

Suhanda, R. D. P., & Pratami, D. (2021). RACI Matrix Design for Managing Stakeholders in Project Case Study of PT. XYZ. *International Journal of Innovation in Enterprise System*, *5*(2), 122–133. https://doi.org/10.25124/ijies.v5i02.134

Swaraj, A. (2019). *Exploratory Research: Purpose And Process*. *2*.

Touran, A., Molenaar, K. R., Gransberg, D. D., & Ghavamifar, K. (2009). Decision Support System for Selection of Project Delivery Method in Transit. *Transportation Research Record: Journal of the Transportation Research Board*, *2111*(1), 148–157. https://doi.org/10.3141/2111-17

Walker, D. (2018). Integrating Project Delivery. *International Journal of Managing Projects in Business*, *11*(2), 548–554. https://doi.org/10.1108/IJMPB-05-2018-166

World Commission on Environment and Development. (1987). *Report of the World Commission on Environment and Development: Our Common Future*. Oxford University Press.

Yassine, A. A. (2004). An Introduction to Modelling and Analyzing Complex Product Development Processes Using the Design Structure Matrix (DSM) Method. *Journal Urbana*, *51*(9), 1–17.

Zeigler-Hill, V., & Shackelford, T. K. (Eds.). (2020). *Encyclopedia of Personality and Individual Differences*. Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3

Zhong, Q., Tang, H., & Chen, C. (2022). *A Framework for Selecting Construction Project Delivery Method Using Design Structure Matrix*.

Appendix I – Question List

Themes / Question Areas	Expected insight from interviewee			
	Client	Designer / Architect	Contractor/Sub-contractors	Supplier / Manufacturer
1. Project Objectives & Motivation	Understand client goals and decision factors (cost, flexibility, market demand).	Understand client briefing and design response.	Understand client expectations translated to site execution.	Understand client requests for modularity/flexibility in components.
- Can you briefly describe the project and its goals?				
- What were the drivers for adaptability?				
- Why was adaptability chosen in this project?				
2. Adaptability in Practice	Understanding the real-world practices of building adaptability from client perspectives	Understanding the real-world practices of building adaptability in design perspectives	Understanding the real-world practices of building adaptability in the execution phase	Understanding the real-world practices of building adaptability in the material support
- At what stage/phase of the project was adaptability discussed into the design and delivery process?				
- What were the main drivers for adaptability in this project? (e.g., client requests, regulation, market trends)				
- Were there any specific design or technical strategies used to enhance adaptability?	Optional	Design strategies for future-proofing.	Construction methods supporting flexibility.	Modular design and production solutions.
- How do you define success for an adaptable building project from your perspective?	Understand the success definition from client perspectives	Understand the success definition from designer perspectives	Understand the success definition from contractors perspectives	Understand the success definition from supplier perspectives
3. Selection of Project Delivery Method (PDM)	Decision-maker perspective on PDM choice.	Influence on design & delivery coordination.	Effect on the project construction	Supplier contract terms and integration into project delivery.
- Which PDM was used in this project? (e.g., Design-Build, Integrated Project Delivery)				
- Was the choice of PDM influenced by the goal of adaptability? If so, how?				
- Were there any adjustments made to the standard delivery process to accommodate adaptability?				
4. Project Activities & Dependencies	Understand decision points and approval flow.	Coordination between disciplines, early design involvement.	Sequencing of site activities to allow adaptability.	Integration of supply chain activities with project schedule.
- Can you describe the **sequence of key activities** from design to completion? (that in your scope)				
- Were there specific **activities** that played a critical role in ensuring future adaptability?				

Themes / Question Areas		Expected insight from interviewee			
		Client	Designer / Architect	Contractor/Sub-contractors	Supplier / Manufacturer
-	How did you manage coordination between design, manufacturing, and construction teams for adaptable solutions?				
-	Were there any specific **activities or dependencies** that caused delays or required reconfiguration?				
-	Were there activities that could have been **improved** to better support adaptability?				
5. Actor Roles & Responsibilities		Client leadership / delegation of responsibility.	Role in ensuring design adaptability.	Execution responsibility and flexibility on-site.	Supplier's role in delivering adaptable components.
-	Who is responsible for adaptability outcomes?				
-	How are responsibilities shared across parties?				
6. Challenges & Barriers		Cost concerns, market risk, and coordination challenge	Design conflicts, regulatory barriers.	Site constraints, coordination difficulties.	Manufacturing constraints, standardization limits.
-	What were the **main challenges** in delivering adaptability within the project?				
-	How were these challenges mitigated?				
-	Were there any specific **activities or dependencies** that caused delays or required reconfiguration?				
7. Reflections & Improvements		Insights for future projects.	Design process improvements.	Construction process improvements.	Supply chain and production improvements.
-	If you were to deliver a similar project again, what would you **do differently** regarding adaptability and delivery method?				
-	Are there **lessons** from this project that you think could inform future projects aiming for adaptability? **(lesson learned)**				