chapter 1 Introduction

1.1 Overview, Purpose, and Structure of the Book

The construction industry stands at a critical crossroads, challenged by persistent inefficiencies, fragmentation, and a slow pace of digital adoption. Despite being one of the world's largest sectors, industry's productivity has stagnated, lagging far behind manufacturing, retail, and other sectors that have embraced digital transformation. These issues not only constrain economic growth but also amplify environmental and social impacts, underscoring the urgent need for integrated, technology-driven solutions.

This book, *5D BIM: A Data-driven Approach to Construction Supply Chains Integration,* aims to provide a comprehensive, practice-oriented roadmap for driving construction efficiency and innovation through the adoption of 5D+ BIM. The text bridges cutting-edge academic research and practical applications, empowering owners, designers, contractors, and suppliers to leverage digital technologies for project delivery, supply chain integration (SCI), and value generation.

This book provides construction professionals and academics with actionable strategies, standards, and implementation frameworks for leveraging 5D+ BIM to tackle key challenges in the construction supply chain—such as information bottlenecks, material flow inefficiencies, cash flow management issues, and fragmented collaboration. The chapters synthesize foundational theory, industry standards, and case studies, equipping readers with both the knowledge and tools to drive organizational changes to realize the full potential of integrated digital project delivery. This book demonstrates how 5D+ BIM has the potential to transform construction supply chains (CSCs) by integrating information, material, and cash flows—eliminating waste and generating value throughout the project lifecycle.

"*5D+ BIM*" refers to building information modeling enriched with both 4D (schedule) and 5D (cost) data, as well as additional dimensions such as sustainability metrics, and procurement data. This integrated approach enables all supply chain participants to visualize, analyze, and optimize construction activities collaboratively.

The structure of this book reflects a deliberate progression from foundational concepts to advanced applications, allowing readers to build expertise systematically:

- **Chapter 1:** Introduction presents an overview of the construction industry's current challenges and segmentation, establishes the growing importance of digital methods, and clearly frames the book's purpose: empowering readers to drive construction efficiency and SCI through 5D+ BIM.
- **Chapter 2:** Background provides a comprehensive overview of construction supply chain management (CSCM), including key definitions, challenges, and emerging integrating solutions such as lean construction, integrated project delivery (IPD), and modularization.
- **Chapter 3:** 5D BIM state of practice explores the latest standards, guidelines, and digital tools for 5D BIM implementation, including National Building Information Modeling Standard – United States (NBIMS-US), Industry Foundation Classes (IFC), and level of development (LOD) frameworks.
- **Chapter 4:** Lifecycle development of 5D BIM discovers frameworks for applying 5D BIM across the entire project lifecycle and review case studies that showcase integration and automation.
- **Chapter 5:** Case studies, learn from real-world projects that demonstrate 5D BIM adoption and supply chain integration, distilling lessons learned and best practices.
- **Chapter 6:** Value proposition of 5D BIM analyzes the benefits and challenges of 5D BIM for all stakeholders, owners, architects, contractors, estimators, and suppliers, supported by current research and industry evidence.
- **Chapter 7:** Blockchain-enabled 5D BIM explores cutting-edge research on using blockchain and smart contracts to automate payments and enable secure data sharing in CSCs.
- **Chapter 8:** Conclusion, integrated cost management with 5D BIM summarizes key findings and provides a roadmap for future research and practical implementation.

In each chapter, readers will follow a structured format comprising Guiding Questions, Answers, Discussion and Conclusion, and References. By the end of this book, readers will:

- Understand the major sources of inefficiency in construction and how digital methods can address them.
- Gain competency in 5D+ BIM technologies, standards, and workflows.
- Be equipped to implement integrated supply chain strategies for improved project outcomes.
- Learn how to evaluate and justify investments in digital transformation for construction management (CM).
- Anticipate future directions in construction digitalization, including the integration of blockchain and artificial intelligence (AI).

This book is a timely resource for anyone seeking to drive efficiency, integration, and innovation in construction through 5D+ BIM. By following the frameworks, standards, and real-world examples presented in the following chapters, readers will be well prepared to meet the challenges of a rapidly evolving industry and to lead the digital transformation of the built environment.

Guiding Questions

1. What are the underlying reasons for inefficiencies and waste in the construction industry? What is the significance of these wastes on triple bottom line (e.g., economy, environment, social)?
2. How can we make the construction industry more efficient?
3. How can construction supply chain integration (CSCI) help mitigate waste and inefficiencies?
4. How have the evolving BIM applications made the construction industry more efficient?
5. What is 5D+ BIM and how can it address some of these critical sources of inefficiencies?
6. How can CSCI help mitigate waste and inefficiencies?

1.2 Construction Industry and Its Current State of Inefficiency

- **Guiding Question #1:** What are the underlying reasons for inefficiencies and waste in the construction industry? What is the significance of these wastes on the triple bottom line (e.g., economy, environment, social)?

The construction industry has developed the reputation for having the lowest productivity of any industry. Since 1945, the construction industry has barely increased its productivity, while other sectors from retail to manufacturing have transformed their efficiency and productivity by 1,500% through embracing digital technologies (McKinsey Global Institute, 2017). Given the magnitude of the construction industry as the largest sector in the world economy, with about $10 trillion spent each year, this lack of progress in productivity costs the world economy. For construction to catch up with other industry's productivity, it has to produce additional value by $1.6 trillion per year, which would be enough to meet about half of the world's annual infrastructure needs or boost global GDP by 2% (McKinsey Global Institute, 2017).

The MGI examined the root causes of poor productivity growth in the construction industry and concluded that the construction industry is highly fragmented, there is a mismatch in risk allocations and rewards, and under-investment in skills development, R&D, and innovation are among the reasons for this poor performance. Unlike the manufacturing industry, each construction project is unique with a different set of team players and compositions; as a result, for each project, a new operating system must be established which makes it very inefficient. Additionally, the contractual silos at different levels of the construction supply chain and lack of systems interoperability hinder communication and data flow. In this fragmented environment, it is difficult to build trust. The current state of fragmentation in the construction industry (e.g., lack of coordination and communication) not only affects productivity but significantly lowers the industry's overall sustainability performance from all three bottom lines. From an economic standpoint, the project will suffer from schedule delays, cost overruns, and quality issues. From an environmental standpoint, additional material waste increases pollution and CO_2 emissions. From a social standpoint, disputes, litigations, and strained relationships are the negative consequences.

1.3 Productivity Booster and Opportunities for Improvement

- **Guiding Question #2:** How can we make the construction industry more efficient?

According to MGI, case examples of innovative firms point out seven areas that could boost productivity by 50%–60%. These are (1) reshape regulation; (2) rewire the contractual framework to reshape industry dynamics; (3) rethink design and engineering processes; (4) improve procurement and supply-chain management; (5) improve on-site execution; (6) infuse digital technology, new materials, advanced automation; and (7) reskill the workforce. They also suggested that the industry should move away from a process-driven project system to a more holistic project operating system with a shift toward standardization, prefabrication, modularization, and mass production (McKinsey Global Institute, 2017) (Figure 1.1).

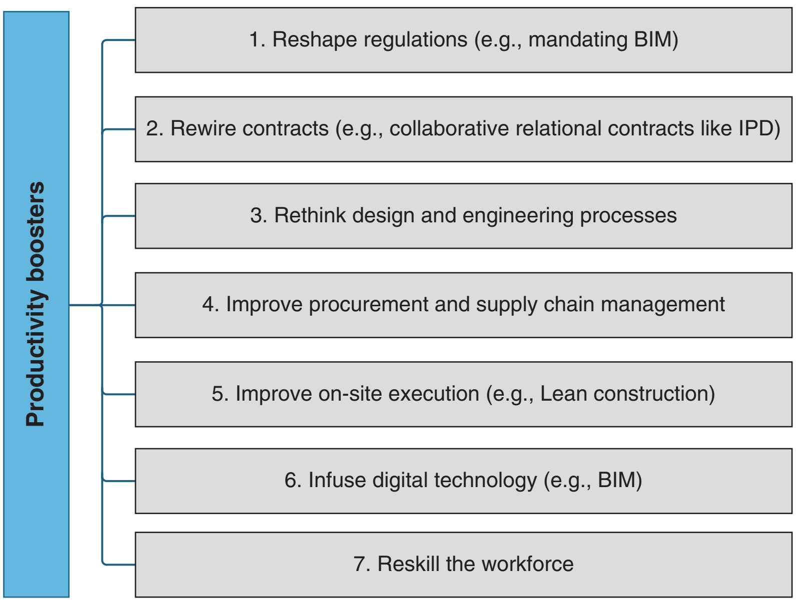

Figure 1.1: Productivity boosters.
Source: Adapted from McKinsey Report 2017.

Specifically, 5D BIM supports the rethinking of design and engineering processes by embedding cost and scheduling data directly within 3D models, allowing for rapid, data-driven decision-making and collaborative workflows that reduce fragmentation (Hardin, 2015; Pishdad & Onungwa, 2024). By linking cost and schedule information to model elements, 5D BIM greatly improves procurement and supply-chain management, making material delivery more predictable and reducing risks of delay and waste (Yoon & Pishdad-Bozorgi, 2022a). The platform also enhances on-site execution, enabling real-time progress tracking and cost forecasting, which minimizes rework and facilitates more efficient project delivery (Pishdad & Onungwa, 2024). Through the adoption of advanced digital technologies, including automation and integration with platforms such as blockchain, 5D BIM acts as a catalyst for industry-wide digital transformation (Yoon & Pishdad-Bozorgi, 2022b). Furthermore, successful 5D BIM implementation requires reskilling the workforce, encouraging professionals to adopt new digital competencies essential for future-ready CM (Sacks et al., 2018). In this way, 5D BIM directly advances five of the seven productivity boosters, targeting the core drivers of cost, schedule, and efficiency improvements in construction.

Emerging practices such as IPD, lean construction, and BIM are effective means for addressing the issue of fragmentation. While these methods are complementary and very well aligned, they each use different mechanisms to promote integration (e.g., contractual, operational, and information technologies, respectively).

The industry has known for some time barriers to higher productivity and ways of overcoming them; however, there is a lack of incentives and a driving force that demands and requires the transformation. And that is the reason why the industry has been in a deadlock. Owners can play an instrumental role in driving this transformation to higher supply integration and efficiency. By clearly specifying the need for SCI and information continuity, the owners can identify the qualified players through a selective procurement system. They can also enforce the new operation and execution requirements through contracts. Owners, especially public owners, are in a strategic position to drive the transformation to CSCI and digitalization.

1.4 Significant Role of CSCI in Construction Productivity

- **Guiding Question #3:** How can CSCI help mitigate waste and inefficiencies?

According to the Construction Industry Institute (CII), lack of SCI and visibility results in delayed delivery of materials and out-of-sequence work, which ultimately lowers overall productivity, delays projects, and increases expediting costs. According to CII (2020), 63% of the average craft laborers is spent off tools. A significant portion of this nonproductive time (32%) can be attributed to waiting on materials and instructions, and for tools and equipment.

Current silos of data across supply chain participants impede visibility of material delivery status. Being able to see where materials are and predict their delivery time is essential for taking corrective actions and completing projects on time. Visibility of information is key to managing material flow, proactive decision-making, and managing risk (CII, 2020). Modern productivity thinking has been focusing on different productivity enhancement efforts, including lean construction, Advanced Work Packaging (AWP), and supply chain information integration to mitigate the risk of disrupted material flow, late material delivery, and out-of-sequence work. AWP is the practice of defining and improving procurement work packages. Indeed, almost all project improvement efforts can benefit from supply chain visibility and integration. Defining key information to be visible and contracting for desired information are essential steps for achieving SCI. Owners and project stakeholders should collectively define their required information for informed decision-making and proper functioning early in the project definition phase. Through collective pull planning, each stakeholder must define their information requirements, the party responsible for providing such information, and the expected information delivery date. Often, time schedules revolve around the delivery and installation of materials. However, the "information delivery" schedule serves an equally, if not more important, role. The absence of information requirement definition, pull planning for data delivery, and contracting for information delivery are the root causes of information silos and lack of supply chain visibility.

1.5 Role of BIM in Enhancing Supply Chain Integration and Boosting Productivity

- **Guiding Question #4:** How have the evolving BIM applications made the construction industry more efficient?

The cost of intermittent data flow, data silos, and poor software interoperability in the construction industry cannot be overlooked. In addition to its impact on material delivery delay, out-of-sequence work, and expediting cost, intermittent data flow is extremely costly. At each information exchange point, if data is not readily available or easily transferable, information gets lost, and additional time and labor need to be spent to look up the needed information up and reenter it manually (Figure 1.1). In 2004, the US National Institute of Standards and Technology (NIST) published a study which quantified the costs caused by poor software interoperability in the US capital facilities industry at $15.8 billion per year (O'Connor et al., 2004).

To overcome this significant economic waste and improve data flow, in 1994, the International Alliance for Interoperability was founded by several software vendors, users, and public authorities around the world, which, in 2004, was rebranded and renamed buildingSMART. The result of their efforts led to the development of a vendor-independent object-oriented data format named Industry Foundation Class (IFC) for exchanging digital building models. In 2013, IFC was adopted as an ISO standard (ISO2013), and now it is enforced by many national guidelines that stipulate the implementation of open BIM (Borrman et al., 2018) (Figure 1.2).

The US National BIM Standard defines BIM as follows: *"A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. The standard seeks to help players in the building space, from architects to contractors to building owners and even realtors and lawyers, get the most out of BIM by streamlining knowledge sharing, collaboration, and file interoperability."* BIM provides information-rich models of the asset that can be used to populate the asset information model. Asset managers rely heavily on the availability of accurate, detailed, and timely information about the asset (RICS, 2020).

- **Guiding Question #5:** What is 5D+ BIM and how can it address some of these critical sources of inefficiencies?

BIM is comprised of three-dimensional (3-D) geometry of building components as well as additional semantic information that conveys x-dimensional (x-D) specifications about the component and/or their

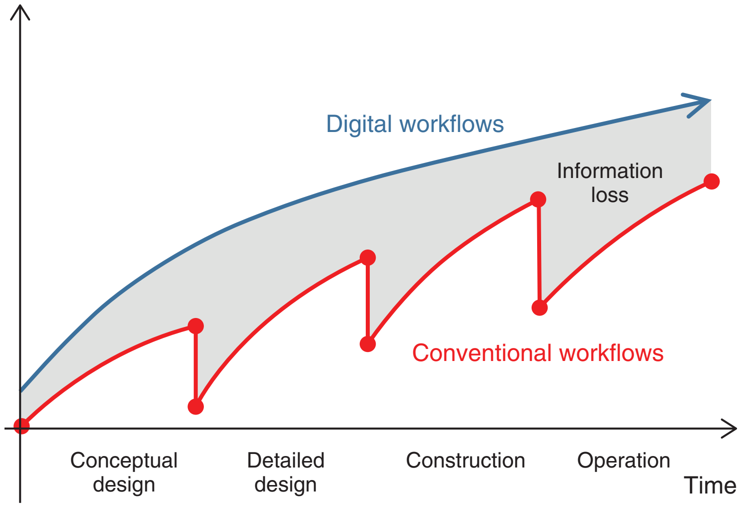

Figure 1.2: Data loss caused by disruptions in the digital information flow.
Source: Adapted from Eastman et al. 2008.

execution. x-D semantic information includes physical characteristics (e.g., type, material, technical property) or spatial information (e.g., space, location, zone), performance data, operation and maintenance data, or cost and schedule information for project execution. Depending on the intended application of BIM, different x-D semantic information or geometry resolution/elaboration, LOD is needed to define its intended purpose. Some widespread applications of BIM include visualization, coordination of disciplines and clash detection, derivation of technical drawings, cost estimation, 4D schedule simulation, and digital handover of building operation and maintenance data.

BIM objects have parametric relationships, and their semantic data is machine readable. Together these two characteristics of BIM enable data analytics (different kinds of simulations) and enable automation of model updates in all representations. For example, if a change is made to the plan view, all other representations, such as elevation, section views, and quantity take off data, automatically get updated to consistently reflect the change made to the model. BIM is the single source of truth from which all its representations derive.

In a project life cycle, there are many stakeholders involved along the supply chain, each utilizing their individualized software to add their discipline-specific data and components to evolving BIM, conduct simulation, and have different data needs from BIM to coordinate and make informed decisions. Given the broad and ad hoc network of participants involved in the supply chain, the only means to achieve seamless data exchange between different discipline-specific BIM models is by making BIM software interoperable. Open BIM refers to interoperable BIM that enables data exchange by following national specifications for a vendor-neutral data exchange format like the IFC data model. Establishment of the open standard like IFC was the first right step toward standardization of data structure models; however, this method needs continued improvement as we still see that some data still gets lost or misinterpreted during data transfer using IFC.

BIM has revolutionized the construction industry through digitalization of facilities, data, and models. BIM increases supply chain information visibility by establishing a shared single source of truth for facility data and execution status. In addition, BIM has enabled seamless data flow along the supply chain if embraced and implemented by all key stakeholders. Enhanced visibility/accessibility/flow of data and increased collaboration make BIM an effective approach to increasing SCI.

1.6 Construction Supply Chain Integration

- **Guiding Question #6:** How can CSCI help mitigate waste and inefficiencies?

The term "supply chain" (SC) was first put forward in 1982 by Oliver and Webber, who described it as a network of organizations in the manufacturing industry that are involved, through upstream and downstream linkages, in the different processes and activities that produce products and services (Asgari et al., 2016; Christopher, 2016; Stadtler et al., 2015). SCM is the systemic coordination of business functions and strategies across the supply chain to improve the performance of the individual companies at different levels (strategic, tactical, and operational) and the entire supply chain (Mentzer et al., 2001; Papadonikolaki et al., 2016; Slack et al., 2010). For managing the supply chain, a series of relatively mature management tools and theories, such as total quality management (TQM), just-in-time (JIT), and lean production (LP), have been proposed and developed (Bašková & Ňarjaš, 2016). In view of the success of the manufacturing industry, some researchers began to adopt and adapt the concept of SCM to the construction sector in the early 1990s (Koskela, 1992). Especially after Bertelsen and Nielsen (1997) and O'Brien et al. (2008) formally proposed the concept of CSCM and systematically expounded it, CSCM was officially regarded as an important research branch of SCM and was widely studied by researchers and practitioners (Lu et al., 2019).

After nearly two decades of development, SCM implementation in the construction sector is still scattered and partial (Gadde & Dubois, 2010). Although we can summarize some specific CSCM research topics in the literature, such as strategic networks, relationship management, trust, lean thinking, knowledge management (Aloini et al., 2012), many scholars may not take CSCM as an independent topic for research. It is difficult to describe the exact definition, the scope, and the major problems to solve. With the acceleration of building informatization and industrialization, the combination of new project delivery models, such as IPD, CM, and engineering procurement construction (EPC), and new technologies, such as BIM, AI, and prefabricated building, has made it possible to build facilities like cars, which highlights the importance of the integration level of construction projects. Information integration, organizational integration, process integration, and system integration in the construction supply chain will become important directions for future research (Fischer et al., 2017).

In the construction industry, supply chain integration (SCI) is regarded as a solution for the issues caused by fragmentation. By integrating processes and organizations, SCI enables an efficient flow of materials, services, information, which results in good stakeholder relationships and ultimately better final building products (Briscoe & Dainty, 2005; Cachon & Fisher, 2000; Flynn et al., 2010; Power, 2005; Wong et al., 2011). Finding a consensus on the definition, scope, and benchmark of CSCI in the existing literature is basically impossible. Stonebraker and Liao (2004) proposed four aspects of understanding SCI, which are breadth of integration, degree of integration, stages of integration, and form of integration.

The SCI is designed to add value to the project through process integration, logistic integration, operation integration, flow integration (material, information, and financial), and collaboration (Eriksson, 2010; Leuschner et al., 2013). Integrated activities like strategic alliance, partnering, information sharing, inclusive decision-making, and collaboration are highlighted as effective in achieving SCI (Cao et al., 2015). The scope of integration usually focuses on the number of participants involved in the integrated supply chain, timing, and duration of integration. Studies from the manufacturing and construction industries have shown that long-term relationships have a significant impact on the continuous improvement of supply chain performance (Bresnen & Marshall, 2000; Pellicer et al., 2012; Saad et al., 2002). A small number of studies have made some attempts at SCI benchmarking. Among them, internal integration (II), customer integration (CI), and supplier integration (SI) are the most used dimensions to measure the success of SCI. These benchmarks refer to the extent to which a company integrates its internal functions, clients, and suppliers, respectively (Cao et al., 2015). Currently, there are some highly referenced SCI measurement scales (Cao et al., 2015; Flynn et al., 2010; Frohlich & Westbrook, 2001; Narasimhan & Kim, 2002), but it is almost impossible to find a scale that is specific to CSCI benchmarking.

1.7 Main Research Areas of CSCI

Existing studies on SCI can be summarized into six major themes, namely (1) adoption of manufacturing theories, (2) benefits of SCI, (3) successful implementation, (4) digitization and utilization of information and communications technology (ICT), (5) contract and relationship governance, and (6) sustainability efforts (Lu et al., 2019).

1.7.1 Adoption of Manufacturing Theories

In the manufacturing industry, the SCM aims to realize the optimization of overall efficiency, improve the market responsiveness, and minimize the internal friction and waste through establishing the strategic partnership among suppliers, manufacturers, vendors, and customers (Chan et al., 2006). The manufacturing sector classifies supply chains into four groups, namely made-to-stock, assembled-to-order, made-to-order (MTO), and engineered-to-order products (Ahmadian et al., 2014). CSCs typically are MTO supply chains, converging all materials to the construction site where the building is assembled (Dallasega, 2018; Dallasega et al., 2018). The difference between the construction industry and the manufacturing industry largely influences the SCM implementation in the construction industry (Chan et al., 2006). Researchers working on CSCI have adopted some theories from manufacturing, which involve lean construction (Dave et al., 2016; Tortorella et al., 2019; Yan & Zhangong, 2012), IPD (Pishdad-Bozorgi, 2012; Pishdad-Bozorgi & Beliveau, 2016b), coordination and synchronization (Hossain, 2009), Relationship Governance Theory (Meng, 2012; Wathne & Heide, 2004), and behavior theory (Cyert et al., 1959; Xue et al., 2007).

1.7.2 Benefits of CSCI

The benefits of SCI involve (1) facilitating coordination and reducing cost, (2) controlling quality, (3) improving inter-organizational relationships, (4) facilitating information sharing, (5) enhancing the competitiveness of organizations, (6) strengthening collaborative forecasting and planning, and (7) improving responsiveness to changes (Christopher & Lee, 2004; McDermotti & Khalfan, 2012; O'Brien et al., 2008; Walker & Rowlinson, 2007).

1.7.3 Successful Implementation

Earlier studies indicated that successful CSCI requires (Briscoe & Dainty, 2005): (1) long-term strategic partnerships (Murray & Kotabe, 1999), (2) strategic management combined with assured information flows (London, 2007), (3) management of relationships and trust (Graham & Hardaker, 2000; Tan, 2001), (4) communications and information sharing (O'Brien, 2004), and (5) sharing common goals (Tan, 2001).

1.7.4 Digitization and Utilization of ICT

Digitalizing construction information and effectively utilizing ICT to integrate the information flow in CSC can improve SC transparency and reduce levels of complexity, thereby improving construction quality while saving cost (Babič et al., 2010). With the rapid development of ICT, the Internet has become the most cost-effective means of driving information sharing and CSCI (Lee & Whang, 2002). Real-time information sharing and analysis through adopting multiple Mobile Internet (M-Internet) applications, such as radio-frequency identification (RFID) technology, ubiquitous sensor network (USN), agent-based technology, and Web-based technology, enable the improvement of CSCI. These ICTs can be used to track materials; communicate in real time, reduce construction time, cost, and waste; and enhance predictability and productivity (Bowden et al., 2006; Kasim et al., 2013; Valero et al., 2015). BIM can serve as the "*digital twin*" of a building that allows for various actors in the CSC to work digitally using their preferred information system and engage in coordination through the exchange of largely compatible information flow via open data standards such as IFCs (Domer et al., 2024; Papadonikolaki et al., 2016). Researchers have been proposing more advanced applications for CSCI, involving ICT-based lean CSC models (Saleh et al., 2024; Tzortzopoulos et al., 2020), context-aware cloud computing BIM (Wong et al., 2014), Global Positioning System (GPS), and BIM-based CSC management system (Deng et al., 2019; Irizarry et al., 2013; Li et al., 2017), and service-oriented SC system (Cheng et al., 2010).

1.7.5 Contract and Relationship Governance

Research on contract governance for CSCI mainly explores the management modes and mechanisms that can facilitate the implementation of integrated CSC. The predominant research themes involve problem-solving mechanisms (Power, 2005), IPD (Pishdad-Bozorgi & Beliveau, 2016b) and integrated contractual agreements (Ghassemi & Becerik-Gerber, 2011). Research on relationship governance focuses on trust, conflict, commitment, reputation, and communication issues among participants in the CSC (Hossain, 2009; Meng, 2012; Ng et al., 2002; Pishdad-Bozorgi & Beliveau, 2016a; Wathne & Heide, 2004; Young et al., 2019). Researchers working in this field attempt to overcome the obstacles of CSCI from the management perspective. Many theories used in this field are adopted from the fields of management science, psychology, and sociology, such as the agency theory, the social capital theory, the transaction cost theory, and the relationship governance theory (Meng, 2012; Wathne & Heide, 2004).

In construction, agency theory typically refers to the contractual and behavioral problems that arise when different parties in the supply chain (owners, contractors, subcontractors, suppliers) pursue their own interests rather than collective project goals social capital theory refers to the idea that trust-based relationships, shared norms, and strong networks among project participants enhance collaboration, knowledge sharing, and integration performance. Transaction cost theory refers to how governance mechanisms (contracts, alliances, vertical integration, relational arrangements) are designed to reduce transaction costs and manage risks in fragmented construction supply chains relationship governance theory refers to the use of informal relational mechanisms — such as trust, shared norms, open communication, flexibility, and mutual commitment — to coordinate and control inter-organizational relationships beyond formal contracts.

1.7.6 Sustainability

Buildings consume a significant amount of energy and account for a large proportion of CO_2 emissions (Ghani et al., 2017). Modern organizational models and approaches are in demand to design CSC with a focus on sustainability (Dallasega et al., 2018). The objective of sustainable CSC is to create buildings by means of energy-efficient, resource-saving, and socially acceptable processes (Carter & Liane Easton, 2011; Dallasega et al., 2018). Kang et al. (2012) proposed a framework for sustainable SCM, which included five key perspectives, namely (1) leadership for knowledge sharing, (2) innovation for product and process corresponding to the lifecycle of sustainable SC, (3) integration of operations by the supply chain and its components, (4) improvement along with the management lifecycle of process, and (5) compliance of socioeconomic requirements and governmental regulations. Shadram et al. (2016) proposed a framework that enables assessment of the embodied energy associated with the building materials in the CSC based on suppliers' Environmental Product Declarations. In addition, through the development of integrated waste management strategies, the RMIT University Research Team demonstrated that integrated CSCs could achieve significant improvements in waste management performance (Construction Waste Lab, 2024).

1.8 Discussion and Conclusion

Literature review shows that only a few research studies directly focus on SCI in the construction field. Many SCI-related studies belong to a broader research area: SCM (Asgari et al., 2016). This is because of the lack of consensus on the concept of SCI. SCI refers to project-level integration practices such as information integration, synchronized planning, operational coordination, and strategic partnership rather than "*soft*" aspects of SCM such as social relationships (Eriksson, 2010; Kache & Seuring, 2017; Saleh et al., 2024; van der Vaart & van Donk, 2008). In other words, SCI focuses on tangible activities or technologies, such as the simultaneous implementations of a new technique or a shared office that enables participants to collaborate and have face-to-face communication (Koolwijk et al., 2018). Integrated project-delivery methods, such as IPD, CM, EPC, project alliance, and partnering are believed to foster integration practices at the project level (He et al., 2024; Lahdenperä, 2012). Successful BIM implementation can also significantly improve the level of SCI by integrating project activities and processes (Wang & Chen, 2023).

All studies aimed at increasing the degree of CSCI focus either on strategic, tactical, or operational aspects of the tangible processes or activities, using a variety of new technologies and tools. Hence, the scopes, objectives, and methods of such research can be diverse, but there is only one goal: deeper integration in CSC. Research on CSCI is still in its infancy (Flynn et al., 2010). Existing literature only shows some scattered attempts based on the research results of the manufacturing sector. The fragmented nature of the construction industry poses a significant challenge to the integration of CSCs (Vrijhoef & Koskela, 2000). First, because of the uniqueness and complexity of the construction process, most construction projects consist of temporary supply chains that need to be reconfigured for each project, which increases the variability and uncertainty of CSCI (Vrijhoef & Koskela, 2000). Second, the proliferation of technologies and tools for integrated CSCs still has some challenges because of their high cost, inflexibility to change, and the lack of system extensibility and interoperability (Cheng et al., 2010; Vrijhoef & Koskela, 2000). Third, the lack of trust between each actor and negative attitudes toward CSC integration are also hindering the integration of CSC (Azambuja & O'Brien, 2008).

Other obstacles involve information accuracy and transparency, security, and CSCI performance benchmarking (Chan et al., 2006; Chen, 2003; Dainty et al., 2001; Valero et al., 2015). In the future, CSCI should be studied as a special topic within SCM. Research on the specific means to improve the degree of integration in CSC is in demand. Promising research directions involve tangible processes and activities such as information integration, schedule synchronization, operational coordination, and organizational relationship linkage.

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