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Thesis title

IMPROVING THE SUPPLY CHAIN OF BUILDING MATERIALS

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Acknowledgement

I would like to express my deepest gratitude to my beloved mother for her unwavering support, love, and encouragement throughout my academic journey. The memory of my late father continues to inspire me, and I am grateful for the values he instilled in me. My sisters, brother, and entire family have been pillars of strength, providing encouragement and understanding.

Special appreciation goes to Dr. Giovanni Zenezini for his invaluable guidance, mentorship, and scholarly insights. His expertise and support have played a crucial role in shaping the trajectory of my research.

I extend my heartfelt thanks to my friends who have been a source of motivation and joy, standing by me during both challenges and triumphs.

In memory of my father and with deep appreciation for the unwavering support of my family, Dr. Zenezini, and my friends, I dedicate this work to their enduring influence on my academic journey.

Abstract

This systematic literature review explores the diverse landscape of technologies employed in the supply chain of construction materials. In an era marked by technological advancements, the construction industry is witnessing transformative changes in its supply chain practices. The primary objective of this review is to comprehensively survey and synthesize existing literature, shedding light on the array of technologies adopted within the construction materials supply chain. A meticulous methodological approach, encompassing research design, search strategy, data collection, and analysis, was employed to ensure a rigorous and unbiased exploration of relevant scholarly and industry sources. The findings of this review not only provide a panoramic understanding of the current technological landscape but also serve as a foundation for future research and innovation within the dynamic realm of construction materials supply chain management. The synthesis of diverse insights and identification of potential gaps in the literature offer valuable implications for practitioners, researchers, and policymakers engaged in enhancing the efficiency and sustainability of construction materials supply chains.

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Acronyms

2SP	Two-Stage Stochastic Programming
AEC	architecture, engineering, and construction
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ATO	Assemble to Order
BIM	Building Information Modelling
BPR	Business Process Reengineering
BREEAM	Building Research Establishment Assessment Method
C&D	construction and demolition
CAD	Computer-Aided Design
CADD	Computer-Aided Design Drafting
CE	Circular Economy
CMSC	Construction Material Supply Chain
CSC	Construction Supply Chain
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
ELECTREE	Elimination and Choice Expressing Reality
EPC	Engineering, Procurement, and Construction
ETO	Engineer to Order
FMEA	Failure Mode and Effect Analysis
GAMS	General Algebraic Modelling System
GBRSs	green building rating systems
GDP	global gross domestic product
GHGs	greenhouse gases
GIS	Geographic Information Systems
HQE	Haute Qualité Environnementale
ICT	information and communication technologies
IM	inventory management
IoT	Internet of Things

IPMA	importance-Performance Map Analysis
LAP	Look-Ahead Plans
LEED	Leadership in Energy and Environmental Design
MAUT	Multi-Attribute Utility Theory
MCDM	multiple criteria decision making
MTO	Make to Order
MTS	Make to Stock
NVA	non-value-adding
PROMOTHEE	Preference Ranking Organisation Method for Enrichment Evaluations
RFID	Radio-Frequency Identification
RFQ	Request for Quotation
RO	Robust Optimization
SCM	supply chain management
SRM	supplier relationship management
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
WMS	Web Map Service

Chapter One: Introduction

1.1 Introduction to the Research Topic

The construction sector serves as a pillar of economic growth by providing the infrastructure needed for society to prosper. The materials employed in their creation are essential to the efficient completion of construction projects. Project deadlines, costs, and overall sustainability are significantly influenced by how effectively the supply chain for these building materials operates. The exploration of the creation of a cutting-edge supply chain model specifically adapted to the special requirements of construction materials is the main goal of this thesis.

Cement, steel, aggregates, and different specialized parts are only a few examples of a wide range of construction materials. For construction projects to be completed without a hitch, their timely and economical purchase, transportation, and distribution are crucial. However, the fragmentation, lack of transparency, and inefficiencies that plague the construction materials supply chain frequently cause delays in projects and raise costs.

This thesis sets out a quest to overcome these issues by exploring numerous technologies and developments that have the potential to completely transform the supply chain for building materials. The aim of this research is to investigate the technologies that improve the flow of building materials, lower waste, and support sustainability by utilizing modern innovations including data analytics, the Internet of Things (IoT), blockchain, and automation.

The modern construction sector is on the verge of a technological renaissance, with supply chain management innovations holding out the prospect of simplifying operations, reducing environmental impact, and improving resource allocation. This thesis' main objective is to identify and comprehend these technologies' function and influence as well as how to include them into a coherent supply chain model.

In the pages that follow, we will take an adventurous tour through the shifting environment of supply chain management in the construction materials sector. We will delve into the complexities of technology-driven solutions, perform in-depth assessments of case studies, and seek to address crucial research questions targeted at determining the future of construction materials supply chains. The overarching goal is to contribute to the industry's long-term success by providing a blueprint for a more efficient and resilient supply chain architecture.

As we progress through our thesis, we must keep in mind the tremendous impacts our study could have on the construction industry, paving the way for a more connected, efficient, and sustainable future.

1.2 Historical Overview of Supply Chain Management in Construction

The management of supply chains in the construction industry has evolved dramatically throughout the years. Historically, construction supplies were procured and transported to construction sites using relatively typical methods. However, with the rise of globalization, advancements in technology, and growing environmental concerns, the need for more complex supply chain management has become increasingly apparent.

Construction supply chains were frequently fragmented in the past, with several intermediaries participating in the procurement process. This fragmentation caused delays, increased prices, and reduced transparency, all of which impacted the effective flow of resources to construction locations. Traditional supply chain models frequently struggled to adapt to the construction industry's dynamic and project-specific needs.

1.3 Current Construction Material Supply Chain Challenges

The modern construction materials supply chain faces numerous obstacles. These are some examples:

1. Fragmentation: The construction materials supply chain often consists of a large number of stakeholders, such as manufacturers, distributors, suppliers, and contractors. This fragmentation can result in breaks in communication, delays, and an absence of coordination.

2. Lack of Transparency: There is frequently a lack of visibility into the movement and condition of items within the supply chain. This opacity makes tracking the location and condition of materials difficult, which may contribute to inefficiencies and mistakes.

3. Inefficiencies: Inefficiencies in transportation, management of inventory, and purchasing procedures can result in time and resources being wasted, compromising project schedules and budgets.

4. Environmental Impact: There is rising pressure on the construction industry to decrease its impact on the environment. Supply chains that are inefficient contribute to excessive resource usage, emissions from transportation, and waste of materials.

1.4 Global Developments and Technological Advances

The worldwide construction sector is changing as a result of numerous trends and innovations in technology:

1. Digitalization: The use of digital technologies such as Building Information Modelling (BIM) has enhanced project planning and collaboration, as well as the supply chain.

2. Sustainability: There is a rising focus on sustainable construction procedures, such as responsible material procurement and transportation.

3. Internet of Things (IoT) and Automation: The Internet of Things (IoT) and automation provide actual time material tracking and more effective management of logistics.

4. Blockchain technology: Blockchain technology allows for greater accountability and traceability in the supply chain.

5. Big Data and Analytics: To improve the operation of supply chains and make decisions based on data, advanced analytics are being deployed.

These worldwide developments and technical advancements serve as a foundation for our investigation of new supply chain models in the construction materials industry. As we progress through this thesis, we will look at how these advancements are impacting the future development of construction materials supply chains as well as how we may use them to tackle current issues.

1.5 Research Objectives and Questions

1.5.1 Research Objectives

This thesis aims to accomplish four overarching goals:

1.Technology Exploration: To thoroughly investigate the many technologies and innovations that are currently being used in the building materials supply chain.

2.Integration Analysis: Investigate how these technologies can be efficiently integrated to create a coherent and efficient supply chain model for construction materials.

3.Improving Efficiency: Identifying techniques and best practices that can lead to increased efficiency, decreased waste, and optimal resource allocation throughout the supply chain.

4.Enhancement of Sustainability: Examine the potential of these technical breakthroughs to promote sustainability by lowering the impact on the environment and resource usage.

1.5.2 Research Questions

To achieve these goals, the subsequent research questions are posed in this study:

1. What technologies and innovations are being used in the building materials supply chain right now? This question serves as the foundation to comprehend the industry's current situation.

2. In what way can these technologies and innovations be effectively combined to create an efficient construction materials supply chain model? This inquiry looks into the practical aspects of coordinating the implementation of various technologies.

3. What are the main obstacles and hurdles to applying these technologies in the construction materials supply chain, and how can they be overcome? Understanding problems is critical for developing effective solutions.

4. How might an effective supply chain model improve the construction materials sector's sustainability? This inquiry delves deeper into the consequences of our research on social and environmental sustainability.

5. What can be taken away from successful case studies in the implementation of driven-by-technology supply chain solutions in the construction materials industry? Real-world examples will provide helpful insights for future implementations.

We hope to give a complete knowledge of the role of technology and innovation in transforming the building materials supply chain by addressing these research issues. Furthermore, the findings of this study will serve as a road map for industry stakeholders looking to improve their supply chain operations and contribute to the construction sector's long-term success.

We will explore each of these concerns in depth in the next sections of this thesis, drawing on a variety of sources, including literature reviews, case studies, and empirical research, to give significant insights and suggestions for practitioners and scholars alike.

CHAPTER TWO: Literature Review

Synopsis

The review explores academic publications published between 2018 and 2022 that focus on various aspects of the building material supply chain. The thorough study covers procurement, logistics, inventory management, and other industry concerns. The investigation of supply chain difficulties, as well as the introduction and effect of emerging technology aimed at addressing these challenges, is essential to this review.

2.1 Overview of Construction Material Supply Chains: Key Components and Processes

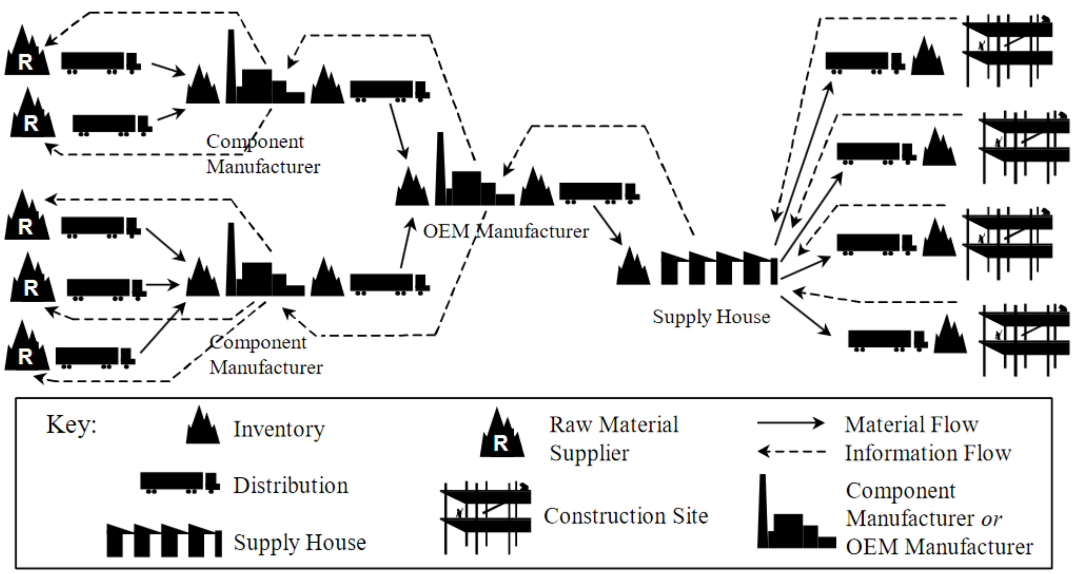

Figure 2. 1: Example of a construction supply chain for a Building Material[1]

2.1.1 Sourcing and Procurement

The procurement function performs a critical role as a bridge between engineering and construction operations in the Engineering, Procurement, and Construction (EPC) sector, relying heavily on external entities. Efficient procurement operations need a continuous interchange of material information both forward and backward throughout the supply chain. This collaborative approach requires rigorous attention from all EPC stakeholders, including not just the major entities but also the suppliers of materials and subcontractors. [2]

2.1.2 Transportation Logistics

Transportation logistics on construction sites involve a wide range of activities. For example, a large building project may require 100,000 deliveries over the course of 12 to 18 months. The construction sector as a whole sees a significant volume of transport-related operations. Notably, logistics and transportation operations add considerably to the overall costs paid in the building area. [3]

2.1.3 Warehousing and Inventory Management

The processes of collecting materials, making purchases, and organizing delivery are critical to the successful completion of construction projects. The total efficiency of construction activities is greatly influenced by factors such as efficient inventory management, the effectiveness of supply units, and the on-time distribution of supplies. Maintaining a sufficient inventory of items that corresponds to demand in both terms of quantity and time is critical to fulfilling project deadlines and maintaining the smooth progression of work. [4]

2.2 Challenges and Dynamics in Procurement and Distribution of Construction Materials

The importance of successfully managing material procurement and logistics for the success of construction projects, particularly in the Engineering, Procurement, and Construction (EPC) business, cannot be understated. Project management in the EPC industry frequently faces various issues, including: [2]

2.2.1 Delay in material supply

Delays have regularly been pointed out as a major barrier in building projects. Delays in material supply can also result in extended periods of inactivity in the construction process. According to studies, the on-site labour force spends around 40% of the overall project length on non-value-added activities such as waiting for authorization to begin duties or for materials to arrive at the site. It is essential to highlight that idle time can lead to substantial negative labour cost variance within production systems, particularly in construction systems. Figure 2.2 illustrates various non-value-adding (NVA) activities commonly observed on a typical construction site. In general, delays resulting from NVAs have been identified as a major contributor to reduced productivity and subpar quality of work in construction projects. Addressing and minimizing these non-value-adding activities is crucial for enhancing efficiency and overall project success.[2]

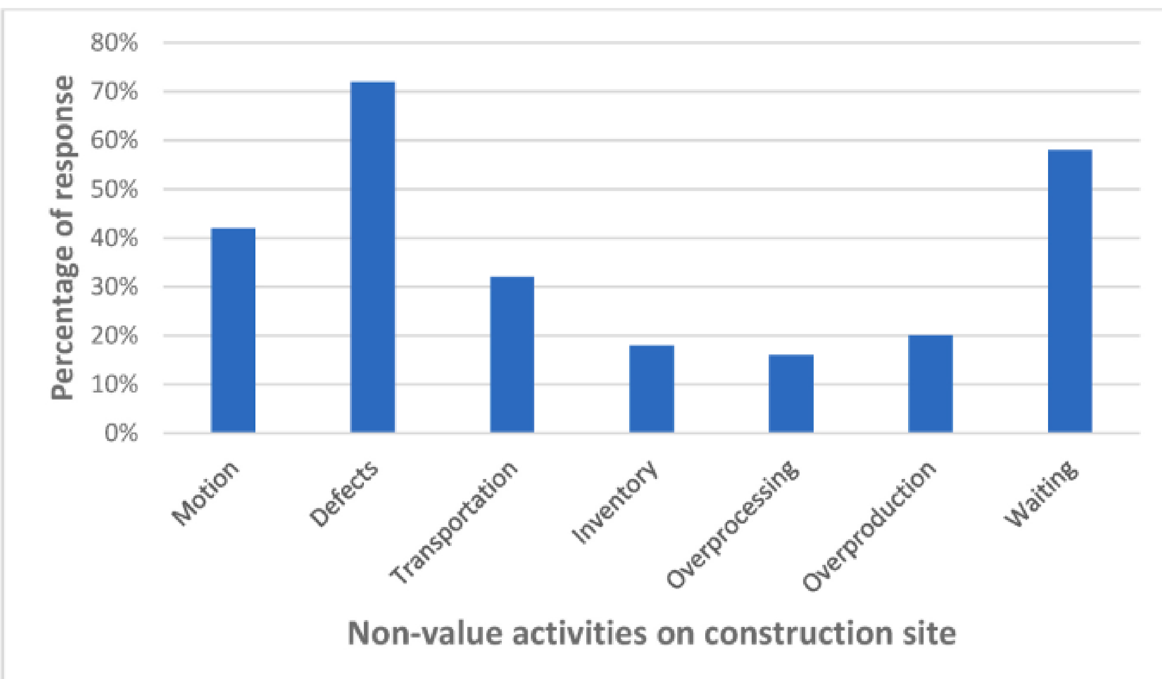

Figure 2. 2:Percentage responses of a typical construction site[2]

2.2.2 Cost overrun

Approximately 13% of the global gross domestic product (GDP) and 7% of the workforce are employed in the construction business globally.[5]

In the construction sector, poor cost control can make it more difficult to accomplish project goals and cause delays in finishing projects on schedule, within budget, and to the required quality standards. A project's original budget specified in the contract is frequently exceeded when an organisation finds it difficult to handle its finances. Throughout the course of the project, mistakes are made, and the cost of fixing these mistakes increases. This leads to an overall rise in the final building costs. Effective cost control strategies are essential to avoid the exhaustion of funds during the building stage, which might result in needless additional expenses to offset exorbitant prices. The importance of comprehending the impact and causes of such budgetary overruns has been emphasised by the numerous studies that have devoted substantial effort to identifying and evaluating relevant elements that have historically led to cost overruns in building projects.[6]

2.2.3 Schedule overrun.

Because construction projects have an inherent connection to future schedules, it is difficult to forecast with precision how they will be carried out. The accurate forecasting of material quantities and their related flows over the course of the project is critical to the success of these efforts. A major obstacle is the lack of knowledge, especially when random material flows through the value stream prevent lean concepts from being widely implemented in the building supply chain. Planning challenges in building projects can result in workflow changes, which in turn cause inefficiencies in succeeding processes and delays, which in turn raise associated costs. As such, it is critical to take into account all possible outcomes as well as the influence of risk factors resulting from supply chain interruptions in the construction industry.[7]

2.3 Inventory Management and Warehousing challenges in Construction Supply Chains

A crucial component of supply chain management is inventory management (IM), which includes the continuous processes of organising, planning, and controlling inventory in order to balance supply and demand while reducing the investment in inventory. IM's core components are supply facilitation, effective storage techniques, and item accessibility with the goal of maintaining an adequate supply without needless overstocking. This procedure starts when the items are received into the warehouse and continues until the products are sold to ultimate consumers.(8)

Inventory Management (IM) is a complex field that involves a wide range of items with different pricing and characteristics. Its primary goal is to satisfy client needs at cost-effective pricing. Lead time, inventory carrying costs, asset management, inventory forecasting, value, visibility, future price forecasting, physical inventory, available space, quality control, managing faulty items, and demand prediction are just a few of the many variables that are included in the large field of integrated marketing. Finding the right balance between these factors is essential to reaching ideal inventory levels, which are a prerequisite for project cost optimisation. The primary issues facing inventory management nowadays are related to holding, ordering, transportation, and maintenance rules. Figure 2.3, derived from the research of Lambert and LaLonde in 1976, provides a detailed breakdown of various categories within inventory costs. Lambert and LaLonde's work has been instrumental in categorizing and understanding the components that contribute to the overall inventory costs. As a result, there have been a lot of research projects that try to come up with workable ways to deal with these issues. Materials-related expenditures can make up between 40% and 70% of the overall cost of construction, which is a significant portion. Because of the wide range of inventory charges, inventory cost estimation is a complicated process that goes beyond standard accounting procedures.[8]

Furthermore, insurances and interests have a big impact on these costs in addition to the previously listed variables. Inventory expenses may be divided into four main categories: capital costs, inventory risk costs, inventory service costs, and storage space costs. There are several kinds of expenditures included in each of these categories. Consequently, determining the amount of space that may be utilised for inventory, looking for ways to reduce costs, and selecting the best supplier based on certain standards are still important factors to take into account.[8]

Problems with the timelines for obtaining the required materials and resources are frequently the main reasons of project delays. Due to work interruptions, these schedule-related issues may result in inefficient use of human resources, supplementary expenses from rising material prices over time, and ultimately, dissatisfied clients.[8]

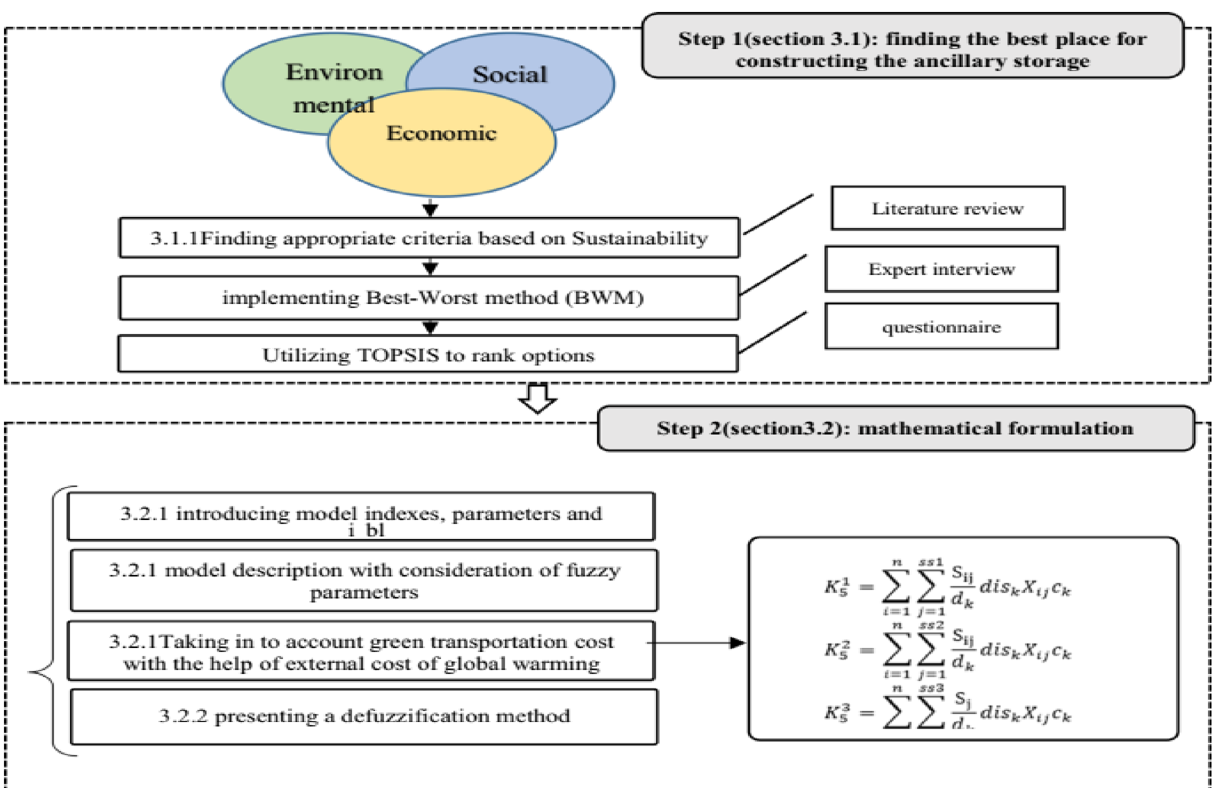

Figure 2. 3: Inventory cost[8]

2.4 Transportation Logistics and Delivery Challenges in Construction Material Supply

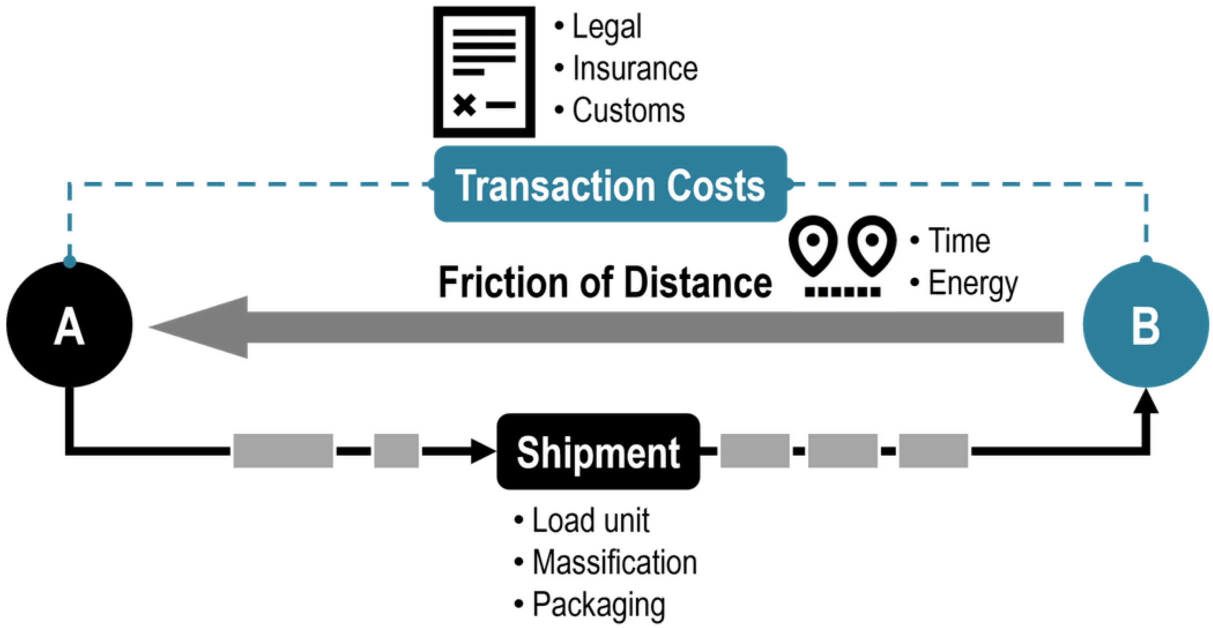

Figure 2. 4: Components of Transport cost (9)

Project cost and schedule are significantly influenced by the locations of building materials and the logistics of transportation. The locations of material sourcing, manufacturing, and storage facilities before they arrive at the building site have a big influence on a lot of different project features.(10)

First off, transportation expenses can account for anywhere from 10% to 20% of the overall project price, depending on the location and distance of the components. When it comes to organising the delivery of building materials, these expenses frequently play a major determining role. As a result, while choosing materials, "location" is an important consideration.(10)

Schedules for the delivery of materials are also impacted by these locations. Transporting materials far away from the construction site typically takes longer, which might delay delivery and procurement, especially for important project tasks. These delays may have a major effect on how quickly a project is completed. As a result, the location of building materials is crucial when choosing materials since it influences both the cost of the resources and the time it takes to transport them.[10]

The sustainability of materials is also influenced by their geographic location because of things like shipping-related noise, dust, and CO2 emissions. CO2 emissions are often higher when transporting across longer distances. Thus, using materials that are local or regional makes sense since it reduces the impact on the environment, boosts the local economy, and highlights the distinctive resources of a place.[10]

Major green construction standards like LEED (Leadership in Energy and Environmental Design) in the United States emphasise the importance of material placement. For instance, in order to lessen the environmental effects of transportation, the LEED standard assesses material location under its credit MRc5 in the "Material and Resource" category. This credit encourages the use of indigenous materials within a specific radius of the project site.[10]

Precise computation of shipping distances is essential, as material transportation expenses account for a large percentage of overall material prices and have a major impact on project timetables and environmental effects. Distance calculation errors may result in skewed cost estimates and poor transportation planning, which may cause project delays or overruns.[10]

The two main issues in precisely determining transportation routes are figuring out the optimal path from the material location to the job site and figuring out how far the chosen route will go. Route decisions are typically influenced by prior experiences, yet they are sometimes arbitrary and less accurate. In addition, selecting the best or quickest path among several possibilities is difficult. Even the shipping route distance may be calculated manually, it takes time and may not produce very accurate results, especially when dealing with a lot of items or extensive shipping distances.[10]

2.5 Supplier Relationship Management and Vendor Selection in Construction

It is imperative to acknowledge the suppliers' vital role in greening the supply chain, especially in light of the uncertain present environment. In this unpredictability, businesses must look for ways to work together with partners in order to make sure that their supply chains continue to be effective and flexible enough to meet changing market needs. By applying the resource-based view's principles, businesses actively seek more cooperation among their suppliers and customers in order to capitalise on the significant resources and expertise that they possess. When two or more separate businesses collaborate to plan and carry out supply chain activities, it is referred to as supply chain cooperation.(11)

Businesses that cultivate strong connections with their suppliers will be better positioned to achieve outstanding performance results. Building strategic supplier partnerships improves performance and helps ensure organizational sustainability and collaborative learning for better risk management. The term "supplier relationship management" (SRM) refers to the range of techniques and protocols used by businesses to communicate and collaborate with their suppliers. (11)

In addition, businesses and organisations are under increasing external pressure from groups that support sustainable supply chains, including regulators, customers, and non-governmental organisations. Businesses are under growing external pressure to prioritise and uphold supply chain sustainability. To maintain sustainable supply chain operations in line with the needs of many stakeholders, a change towards establishing collaborative partnerships and executing efficient supplier relationship management methods is important. (11)

The process of selecting suppliers include businesses finding, assessing, and signing agreements with suppliers. This procedure is extremely important to the success of any organisation and consumes a large amount of a company's financial resources. Its main goals are to reduce procurement risks, maximise the buyer's total value, and cultivate long-lasting partnerships with suppliers.[12]

Enhancing a company's competitiveness through the selection process necessitates evaluating many alternative suppliers according to distinct criteria. A key component of supply chain management (SCM), supplier selection is an example of a multiple criteria decision making (MCDM) problem that has both qualitative and quantitative elements. Reduced purchasing costs, more profitability, faster product lead times, higher customer satisfaction, and more competitiveness may all result from a well-executed supplier selection strategy. It has thus turned into the centre of attention for all purchasing organisations. But choosing a supplier doesn't have to follow a set formula; instead, it should be customised for each unique circumstance. [12]

The performance of a business can be directly impacted by a poor supplier selection decision, which can lead to losses across the supply chain. Purchasing managers still have difficulty selecting the best supplier, especially in the current dynamic environment when selection criteria are constantly changing. Usually, there are three important phases in the procedure. When pricing is no longer the main consideration, the first step is to set criteria, which frequently include quality, delivery performance, cost, and capabilities. The particular purchase scenario will determine which criteria are best to use. The second is administering a questionnaire survey, which entails weighing criteria and evaluating the findings. The primary requirements, supporting requirements, and a study of other supplier selection parameters are all included in this survey format. Lastly, using a multi-criteria decision-making process to select the top provider. [12]

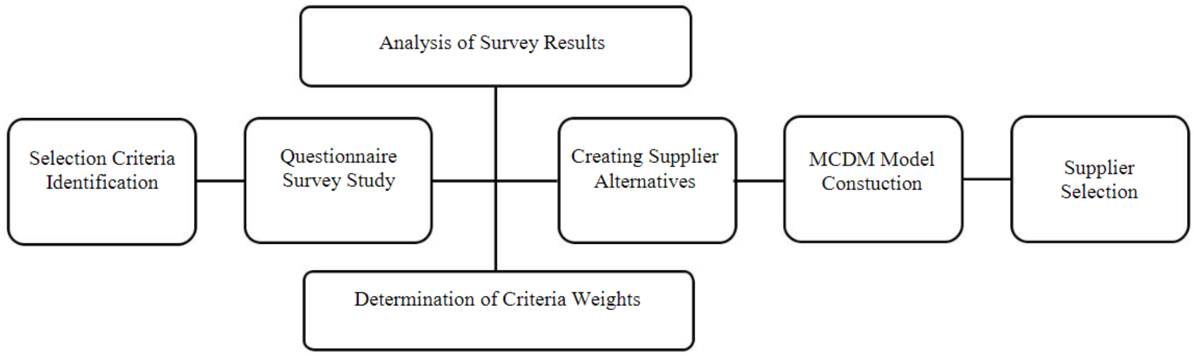

Figure 2. 5: Supplier selection steps*(12)*

Finding the best supplier who can provide the necessary high-quality goods or services at the correct cost, in the proper amount, and in the allotted time is the main goal of a well-designed supplier selection process. One of the most important organisational functions, this procedure is overseen by the procurement department. Therefore, it is essential that the buying manager create and execute a productive procedure to find suitable vendors for commercial contracts. (12)

The four main phases that make up the supplier selection process are as follows and are shown in Figure 2.6: (12)

A. Selecting the subcontracting approach: This first phase is selecting between partial subcontracting and turnkey services, in which the provider completes the assignment entirely. Prior to completing the labour contract, it also entails determining the price strategy. (12)

B. Forming the bidder's list and establishing the preliminary qualifications: In this process, the basic requirements and qualifications for potential suppliers are established. A list of qualified bidders is generated based on these requirements. (12)

C. Request for Quotation (RFQ) preparation and bid analysis: Creating the RFQ document, which includes the necessary specifications, and requesting bids from possible vendors are the tasks involved in this step. After bids are received, a thorough study is carried out to assess and contrast the submissions. (12)

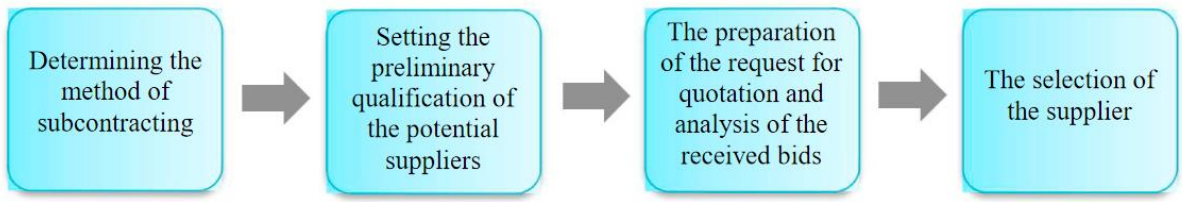

Figure 2. 6: Supplier selection process[12]

The first step in the supplier assessment process is for the buyer to specify the precise "dimensions" or criteria that will be applied. [12]

The role and structure of the buying function have changed over time, especially in the 1990s when the issue of supplier selection became crucial to building a successful supply chain system. The process of selecting a supplier is not standardised, therefore it depends on a number of variables and involves different approaches. Businesses have a wide range of methodological options depending on their products, expectations, criteria, and sector, as each supplier selection is unique. The choice of methodologies has a major impact on the results and the selection process as a whole. Therefore, it is crucial to comprehend which approaches are appropriate in which circumstances. [12]

When opposed to qualitative approaches, quantitative methods usually demonstrate a more defined methodology. Currently, integrated models for supplier selection combine qualitative and quantitative approaches; prior to 2003, these methods were mostly quantitative. Different supplier selection techniques may be divided into several groups and subgroups. Fuzzy logic is used, for example, in the Cluster Analysis prequalification technique. Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Outranking method with Elimination and Choice Expressing Reality (ELECTREE), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organisation Method for Enrichment Evaluations (PROMOTHEE), and Multi-Attribute Utility Theory (MAUT method) are examples of categorical methods. [12]

Some techniques, including Total Cost of Ownership and Activity-Based Costing, are cost-based. Linear programming, goal programming, and multi-objective linear programming are examples of mathematical programming techniques. Data Envelopment Analysis is used as a prequalification technique. Artificial Neural Networks and Case-Based Reasoning are two examples of artificial intelligence approaches. Combination techniques like mathematical programming plus TCO, AHP + linear programming, MAUT + LP, ANP + TOPSIS, or fuzzy TOPSIS have evolved as supplier selection continues to progress. An overview of the various supplier selection techniques and their categorization is shown in Figure 2.7. [12]

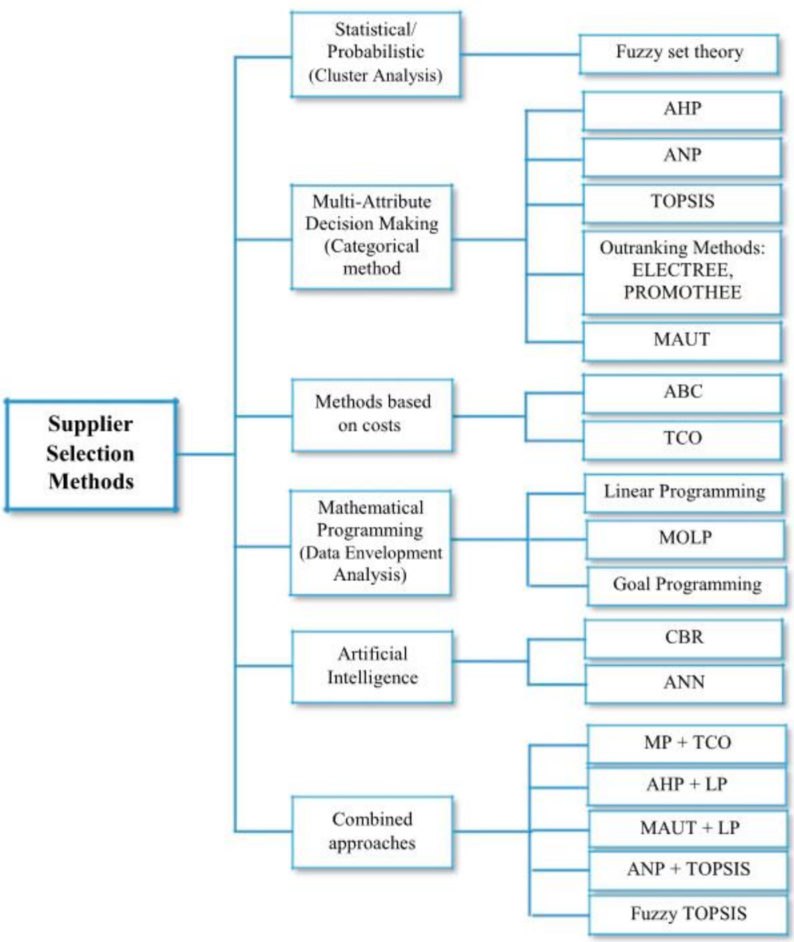

Figure 2. 7: Classification of the supplier selection methods[12]

2.6 Risk Management and Resilience Strategies in Construction Material Supply Chains

Construction projects are inherently complex, involving intricate relationships among various stakeholders, and thus, are susceptible to numerous risks throughout their lifecycle. Managing these risks effectively within the project's supply chain is paramount to prevent potential time and cost overruns, which, if not controlled, can lead to project failure. Both industry practitioners and scholars underscore the heightened risk exposure of construction projects in comparison to other industries, owing to their unique complexities.(13)

The diverse range of risks inherent in construction projects can result in performance reductions, escalating costs, scheduling delays, and, ultimately, project failures. Recognizing and proactively addressing these risks are crucial aspects of successful project management in the construction industry. (13)

Supply chain risks in construction can be broadly categorized into two types: internal risks originating from within the supply chain networks and external risks arising from the surrounding environments. Numerous studies have explored the application of risk analysis methodologies in construction supply chains, particularly in engineering projects that involve route analysis and logistics simulation modelling across the construction supply chain. (14)

Various methods, including Analytic Hierarchy Process (AHP), fuzzy AHP, Logistics Simulation Modelling, and Failure Mode and Effect Analysis (FMEA), have been extensively utilized for risk analysis in construction projects due to their ability to provide accurate results. For instance, researchers have employed AHP and Risk Map methods to manage risks in construction projects, identifying critical risk variables such as material availability, human resource skills, delivery unit availability, material quality, credit facilities, and weather conditions. (14)

The FMEA approach is commonly used for assessing risk events and agents by considering factors like severity and occurrence. Severity indicates the impact or seriousness when a failure mode occurs, offering a comprehensive perspective on the potential consequences of identified risks in construction supply chains. (14)

2.7 Sustainability and Environmental Concerns in Construction Material Procurement

The housing crisis and climate change mitigation provide a double-edged sword for the building industry.(15)

Because human activity releases large amounts of greenhouse gases (GHGs) into the atmosphere, it is one of the main causes of climate change. This is especially true of the building industry. This sector was expected to account for almost one-third of global greenhouse gas emissions by 2021, consuming over 40% of the world's available energy. Buildings' development and operation are the sources of these pollutants. (15)

The industry is focusing its efforts on reducing the energy consumption and environmental effect of buildings in response to this urgent challenge. Improving the design stage of building projects and utilising energy-saving techniques to decrease the industry's total environmental impact are two of the main areas. The goal is to create plans that make it possible to build and run buildings with the least amount of energy use and the least amount of environmental effect. (15)

In order to lessen its impact on the environment, the construction sector uses green supply chain management (SCM), which entails a number of operational adjustments. Supply chain managers have the ability to prioritise sustainable purchasing, adopt environmental standards, apply eco-design techniques, and integrate closed-loop systems and recycling. Measuring the influence on the environment is essential for risk management and performance evaluation in the supply chain.(16)

Changes to building contracts are necessary to promote green procurement in the industry. Green standards for design, contractor selection, and operator tenders should be included of these adjustments. Pre-qualification standards and bid assessments must take the environment into account. To further promote eco-friendly activities, warranties covering green innovations—which can come with greater risks—should be required. (16)

Green supply chain management (SCM) demands both operational and strategic management skills as well as a persistent commitment to implementing new procedures. Organisational cultural changes are also essential. Engaging sustainability specialists for projects may provide invaluable knowledge in guaranteeing the successful integration of sustainable practices. (16)

Standards and regulations are essential for promoting change. Rules show how seriously governments take environmental issues, but standards offer direction and comparison. Comprehensive green procurement rules and industry certification programmes are thought required to promote Green SCM in the building sector. Publicly accessible databases that provide information on the environmental performance of products and highlight effective Green SCM techniques in the construction sector may improve knowledge exchange and accessibility within the sector. (16)

Green Building Rating Systems: In recent years, a number of green building rating systems (GBRSs) have emerged in an attempt to assist minimise these emissions. concentrating on the following in Europe: Haute Qualité Environnementale (HQE), Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), Building Research Establishment Assessment Method (BREEAM), and Leadership in Energy & Environmental Design (LEED).(17)

Numerous EU nations have created their own GBRSs using four distinct approaches (refer to Table 2.1 and Figure 2.8): (17)

Country	GBRS Name	Organization	Starting	Version
Austria	TQB 2010	OGNB	2010	National
	BREEAM AT	DIFNI		National
Czech Republic	SBToolCZ	IISBE Czech/CIDEAS	2010	National
France	HQE	HQE	1997	International
Germany	DGNB	German Sustainable Building Council	2008	International
	BREEAM DE	TÜV SÜD DIFNI	2011	National
Italy	LEED Italia	Italy GBC	2006	National
	ITACA	IISBE Italia	2004	National
The Netherlands	BREEAM NL	Dutch GBC	2011	National
Norway	BREEAM NW	Norwegian GBC	2011	National
Portugal	SBToolPT	iiSBE PT	2009	National
Spain	VERDE	Spanish GBC	2011	National
	BREEAM ES	ITG	2010	National
Sweden	BREEAM SE	Swedish GBC	2011	National
	Miljöbyggnad		2011	National
Switzerland	BREEAM CH	DIFNI	2011	National
	Minergie ECO	MINERGIE	1998	National
United Kingdom	BREEAM	BRE	1990	International
	HQM		2015	National
	CEEQUAL		2011	International

Table 2. 1: List of the most representative GBRS within EU[17]

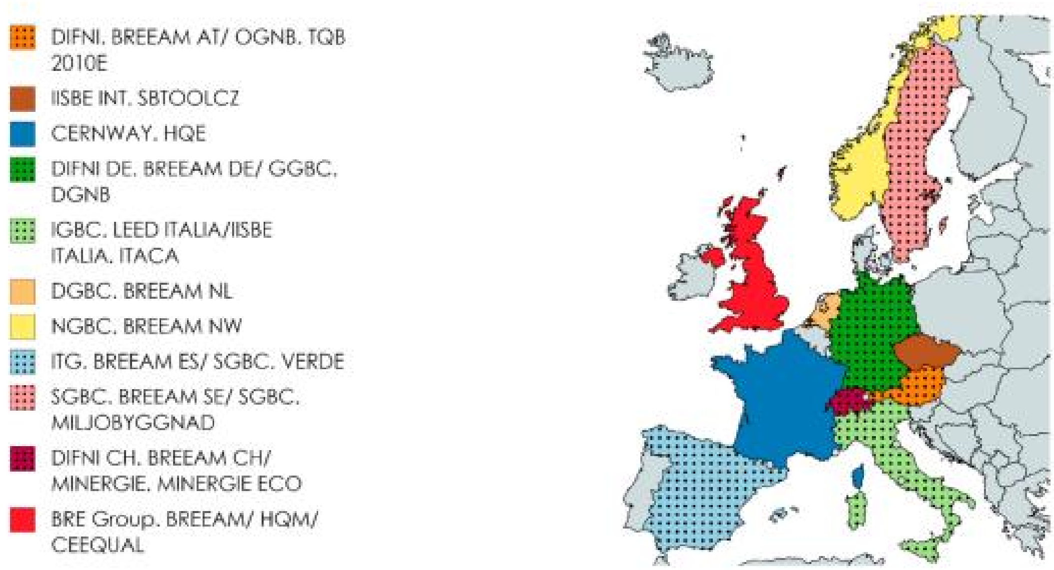

Figure 2. 8: Map of most representative GBRS within the EU[17]

The building sector has been investigating greener techniques for targeted demolition in an effort to reduce waste production at its origin. But there's an urgent need for a more concentrated approach to waste reduction in the design stage. 'Modular design,' investment in waste reduction, and financial incentives are among the key elements identified at this stage for waste reduction.[18]

Waste recovery is still a reliable technique, but recycling is a more focused way to deal with resource shortages and related environmental problems. Recycling garbage from construction and demolition (C&D) projects is very useful in reducing the demand on natural resources. When recycled materials are used in building, the need to extract raw resources is greatly reduced, which helps to mitigate the issue of material depletion and environmental issues. [18]

Since the late 1970s, a few European nations have been in the forefront of ecological practices by incorporating recycled concrete aggregates. Even though employing recovered C&D waste products is legal and technically feasible, most building projects still don't use them extensively. Studies reveal a reluctance on the part of stakeholders to reuse and incorporate recovered construction and demolition waste goods. Conventional materials continue to be preferred in both low-grade and high-grade applications. [18]

Therefore, a paradigm change in the business is desperately needed to go from the customary dependence on conventional resources to a more widespread usage of recycled materials. In order to accept and prioritise the use of recycled C&D waste products in building projects, there has to be a shift in the general mentality. [18]

2.8 Evolving Trends and Industry Shifts Impacting Construction Material Supply Chains

Since the introduction of structural analysis software in the 1970s, the construction sector has been a pioneer in the use of information and communication technologies (ICT). In the 1980s, Slovenia, for example, adopted similar ideas and created its own structural analysis programmes at the IKPIR Institute. The 1990s saw the emergence of construction informatics as a separate field of science and study.[19]

The introduction of Building Information Modelling (BIM) software in the early 21st century, which addressed the difficulties of structured information interchange on construction goods, was one of the significant turning points. By integrating digital objects as the fundamental information unit and so changing the old practice of utilising drawn lines for information display in engineering, BIM eventually supplanted Computer-Aided Design (CAD) and Drafting (CADD). [19]

These days, commercial software greatly facilitates organised information management, which is increasingly commonplace in the building and architectural industries. Because of its advantages and increasing maturity, BIM is starting to be mandated in several nations. [19]

Construction technology is evolving in line with other sectors. It began with the release of general-purpose software and advanced to business information systems that were backed by higher-level frameworks and databases. But historically, people have entered data into information systems and made decisions based on digital analysis, serving as an interface between them and the outside world. [19]

A big change was brought about by the introduction of technologies that fell under the "Internet of Everything" banner. Direct connections between digital systems and the physical environment were made possible by sensors and controllers, which minimised the need for human intervention in these interactions. This change ushered in a new age of digital transformation and automation in the construction sector and created the foundation for Industry 4.0. [19]

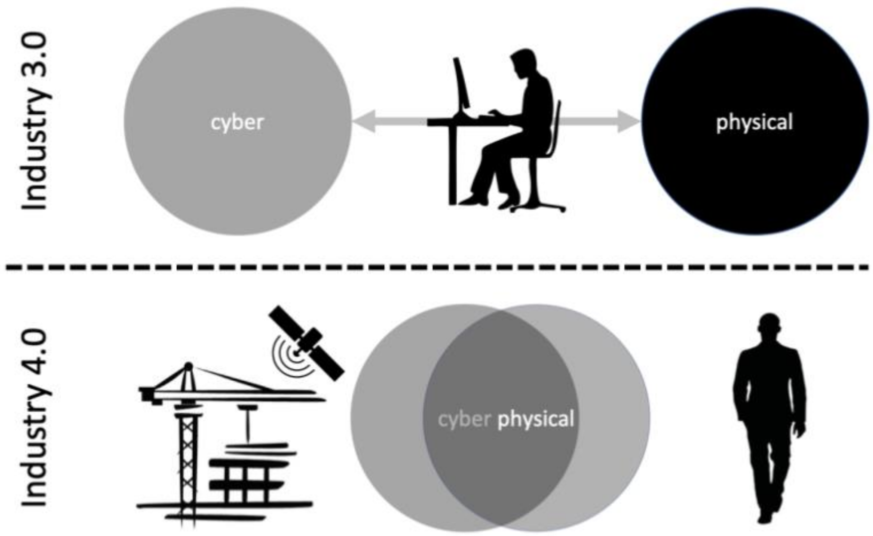

Figure 2. 9: The difference between the third and the fourth wave of the industrial revolution(19)

Aiming to replace the conventional notion of discarding products after their useful lives with practices focused on reducing, reusing, recycling, and recovering materials throughout the production, distribution, and consumption processes, the Circular Economy (CE) is an economic system built on business models. This change in strategy reduces the total amount of waste produced during the manufacture and processing of raw materials. Adopting the CE notion means shifting one's perspective from seeing waste as an issue that has to be solved to seeing it as a resource.[20]

CE is praised as a strategy that promotes both economic growth and environmental impact reduction. The concept of "circular economy" was mentioned in Kenneth Boulding's 1966 book "The Economics of the Coming Spaceship Earth," even though it wasn't named that way. But Walter Stahel and Genevieve Reday first presented the idea of a circular economy in a research report they submitted to the European Commission in 1976. Their examination of how labour may be substituted for energy in the building and automobile industries established the foundation for the CE idea. [20]

Since then, CE has become widely acknowledged in the academic community, the government, and other organisations. Germany, Japan, China, and other European nations have created laws to put CE ideas into practice. Preconstruction, construction and building rehabilitation, collection and distribution, end-of-life, and material recovery and manufacturing are the five essential phases that make up the CE system in the construction and demolition sector. This study explores recent research improvements and achievements in the field of material recovery and manufacturing. [20]

Life cycle stage	Circular economy aspect
Design	DfD Design for adaptability and flexibility Design for standardisation Design out waste Design in modularity Specify reclaimed materials Specify recycled materials
Manufacture and supply	Eco-design principles Use less materials/optimise material use Use less hazardous materials Increase the lifespan Design for product disassembly Design for product standardisation Use secondary materials Take-back schemes Reverse logistics
Construction	Minimise waste Procure reused materials Procure recycled materials Off-site construction
In use and refurbishment	Minimise waste Minimal maintenance Easy repair and upgrade Adaptability Flexibility
End of life	Deconstruction Selective demolition Reuse of products and components Closed-loop recycling Open-loop recycling
All stages: management of information including metrics and datasets	

Table 2. 2 Circular Economy aspects across a building's life cycle stage [21]

Chapter Three: Methodology

3.1 Introduction to Methodology

This section focuses on the methods used for the systematic literature review, which is a critical component of this research. The selection of a systematic literature review is based on its capacity to satisfy the study objectives of developing a realistic supply chain model for building materials.

3.1.1 Methodology justification

The use of a systematic literature review approach is based on its inherent qualities that correspond to the study objectives. This comprehensive methodology enables a complete analysis of existing knowledge and practises in building material supply chain modelling. The following main points highlight the rationale for using this methodology:

3.1.1.1 Study Objectives Relevance:

The primary objective of this study is to gain comprehensive insights into current research on supply chain models for building materials. Employing a systematic literature review proves to be an ideal approach for achieving this goal as it facilitates the discovery, analysis, and synthesis of relevant material in a systematic and comprehensive manner. This method ensures a thorough exploration and examination of the existing body of knowledge on supply chain models in the context of building materials.

3.1.1.2 Comprehensive Exploration:

Given the complexity of supply chain modelling and the diverse array of literature sources, including academic publications, industry reports, and pertinent conference proceedings, a method capable of handling such diversity is essential. The systematic literature review proves to be the appropriate technique in this context, enabling the integration of a broad spectrum of sources. This inclusivity ensures a comprehensive understanding of the complex issue of supply chain modelling in the context of building materials.

3.1.1.3 Identification of Gaps and Trends:

By systematically evaluating current literature, this technique serves to identify gaps and trends in supply chain modelling for building materials. The insights derived from this analysis will play a crucial role in informing the development of an innovative and efficient supply chain model tailored to the specific needs of the building materials sector.

3.1.2 Advantages and Constraints

It is crucial to acknowledge both the advantages and limitations inherent in the chosen methodology:

3.1.2.1 Advantages:

Comprehensive and methodical approach: This ensures the thoroughness of the review process.

Transparency and replicability: The systematic nature of the process enhances transparency and facilitates replication.

Synthesis of varied sources: The methodology enables the synthesis of information from diverse academic and industrial sources.

Informed decision-making: The comprehensive evaluation supports evidence-based decision-making in the development of the supply chain model.

3.1.2.2 constraints:

Potential publication bias: The reliance on published literature may introduce bias due to the selective nature of publications.

Language restrictions: The review's focus on English-language publications may result in the exclusion of valuable contributions in other languages.

Subjectivity in quality assessment: Despite having defined criteria, the process of quality assessment may involve some subjectivity.

The forthcoming pages of the methodology section will comprehensively delve into various aspects, providing detailed insights into the research design, search strategy, data collection and screening, data extraction and quality evaluation, data analysis, ethical considerations, and limitations. This meticulous exploration aims to establish a robust foundation for the development of an innovative supply chain model for building materials through a rigorous and systematic literature assessment.

3.2 Research Design and Framework

3.2.1 Research Questions and Goals

Prior to exploring details of the systematic literature review, it is important to clarify the research questions and goals that function as guides for this undertaking:

1. What existing literature exists about supply chain models for building materials?
2. What technologies are used in the supply chain within the construction industry?
3. What gaps or opportunities for development in the literature have been identified?

Research Objectives:

The primary goal of this study is to provide a thorough assessment and examination of the extant literature pertaining to supply chain models in the construction materials industry. This involves doing a comprehensive and methodical analysis of all available literature about the technologies utilised in the building material supply chain, with the aim of closely examining and assessing the results obtained from these sources. Gaining understanding of the status of research at the moment, spotting trends, and addressing any holes or areas that might need development in supply chain models and technological applications for the construction sector are the goals.

3.2.2 The Framework for Systematic Literature Reviews

The framework for systematic literature reviews adheres to best practices and widely accepted standards. The elements of the framework were purposefully designed to ensure accuracy and comprehensiveness:

3.2.2.1 Criteria for Inclusion and Exclusion:

Inclusion Criteria: The literature that is taken into consideration for this systematic review must have been published after 2018 and directly relate to supply chain modelling for construction materials.

Exclusion Criteria: Any literature that does not fit within the parameters of the study, such as publications that deal with other subjects or industries, will not be taken into account for this review. Examples of rejected titles are :

1. Re-engineering a construction supply chain: a material flow control approach (Paul Childerhouse, Jayne Lewis, Mohamed Naim and Denis R. Towill) published 2003.[22]
2. Measuring the invisible A key performance indicator for managing construction logistics performance (Fei Ying, John Tookey and Jeff Seadon) published 2017.[23]

These inclusion and exclusion criteria serve as sentinels for the systematic literature evaluation, allowing only the most relevant and current resources to contribute to the research. They protect the study's integrity and relevance by guaranteeing that the findings are carefully calibrated to the subtleties of the supply chain modelling area in the building materials industry.

3.2.2.2 Literature Search approach:

The method for doing a literature search is carefully designed to guarantee completeness and accuracy. It includes a wide range of keywords and search phrases that are especially related to construction materials and supply chain modelling. An extensive search is carried out using a variety of academic databases, journals, conference proceedings, and industry reports in order to maximise coverage.

3.2.2.3 Screening and Selection Process:

In order to find possibly relevant content, a thorough assessment of titles and abstracts is the first step in the screening process. Full-text articles are then subjected to an extensive assessment in order to establish eligibility according to predetermined inclusion and exclusion criteria.

3.2.2.4 Data Extraction and Quality Assessment:

Data extraction is the methodical technique of extracting information from specific literary sources using pre-established categories. In order to guarantee reliability and robustness, each source's quality is simultaneously and thoroughly evaluated according to predetermined criteria. When disagreements occur during the extraction of data or the assessment of quality.

3.3 Search Methodology and Data Sources

3.3.1 Search Methodology

3.3.1.1 Search Terms and Keywords

Developing a comprehensive search strategy is critical to the systematic literature review. This approach has been carefully designed to include all relevant literature on supply chain modelling in the building materials industry. Among the search strategy's main components are:

1. Keywords and Search phrases: An extensive collection of keywords and search phrases covering a wide range of ideas associated with supply chain modelling, construction materials, and other subjects has been assembled. Terms like:
    A. logistics in construction.
    B. construction materials supply chain.
    C. inventory management.
    D. Block chain in construction industry.
    E. Green Supply chain.
    F. Sustainable supply chain.
    G. Innovation in construction industry.
    H. BIM in construction industry.
    I. Procurement of construction material.

    are a few examples.
2. Boolean Operators: The intelligent application of Boolean operators (AND, OR, NOT) makes it easier to combine phrases effectively and guarantees that search results are thorough as well as relevant.

3.3.1.2 Database and Source Selection

To guarantee both the breadth and depth of the assessment, the search technique makes use of a wide range of databases and sources:

1. Academic Databases: Scholarly publications and research are found through the use of reputable academic databases, such as the Politecnico di Torino database, Scopus, and Emerald Insight.

2. Industry Reports: By combining industry-specific sources, such as publications and reports from building groups and trade associations, practical insights from the field are recorded.

3. Journals and Conference Proceedings: Reputable journals and conference proceedings about supply chain management and construction materials are a good place to look for insights from academic and industry conferences.

3.3.2 Process of Search and Retrieval

Following a methodical approach, the search strategy and literature retrieval are carried out as follows:

1. Initial Searches: Using the specified keywords and search phrases, searches are started in a few databases.

2. Preliminary Screening: To determine their applicability to the research, titles and abstracts of documents that have been retrieved are first screened.

3. Full-Text Collection: During the first screening, records that are thought to be possibly relevant are the source of full-text articles. This makes a more thorough review possible.

The search technique and data sources were chosen in a methodical manner to guarantee thorough coverage of the most recent research on supply chain modelling in the building materials industry. The screening, selection, and data collection procedures will be covered in depth in the following sections.

3.4 Data gathering and screening

3.4.1 Data Collection Methodology

The data collection process for this systematic literature review is carefully designed to guarantee a comprehensive and methodical approach to finding and obtaining pertinent content. This process follows accepted guidelines and industry best practices.

3.4.1.1 The First Search and Retrieval

Many literature records are produced by the first search, which is conducted according to the search technique. Every record that is retrieved is methodically stored, preserving an explicit record of the original database, publication date, and source.

3.4.1.2 Title and abstract screening

Titles and abstracts are first screened in order to determine each item's relevancy. Records that blatantly fail to fulfil the predetermined inclusion criteria are now removed.

3.4.1.3 Full-Text Evaluation

Records that pass the title and abstract screening and are thought to be possibly relevant are subjected to a comprehensive full-text review. During this step, each article's content is thoroughly examined to see if it meets the inclusion requirements.

3.4.1.4 Maintaining Records

Extensive records are kept at every stage of the data collection procedure, detailing the reasons for exclusion. During the review process, any inconsistencies or doubts are promptly documented for resolution.

3.4.2 Dealing with Duplicate Entries

An attempt is made to locate and resolve duplicate entries:

A. Multiple database searches that provide duplicate items are found and combined.
B. Every entry is evaluated for uniqueness with the goal of removing duplication from the final dataset.

This methodical, open, and transparent approach to gathering and screening data guarantees an exhaustive, exacting, and objective assessment procedure.

3.5 Data Extraction

This review of the literature mostly depends on a systematic data extraction approach created to systematically gather relevant data from different publications and sources. The steps below explain the data extraction procedure:

3.5.1 Predefined Categories

Predefined data extraction categories have been established in accordance with the aims and objectives of the study. These include supply chain elements, modelling strategies, barriers, and noteworthy discoveries.

3.5.2 Reliability and consistency

Extensive data extraction forms are utilised in order to methodically capture data from every chosen source. This guarantees a rigorous and standardised procedure for data extraction.

3.5.3 Documentation and verification

The content that has been extracted is thoroughly documented, including key findings, methods used, relevant statistics, and bibliographic data. The collected data is cross-checked against the original source to reduce mistakes. The rigorous documentation and verification procedure improves the derived data's correctness and dependability.

3.6 Data Synthesis and Analysis

3.6.1 Data Synthesis

The process of arranging, classifying, and integrating data obtained from the selected literature is known as data synthesis. This phase is essential for obtaining insightful knowledge and addressing the goals and problems of the research. The process for synthesising data is as follows:

3.6.1.1 Thematic Investigation

A key component of the data synthesis technique is thematic investigation. The use of thematic analysis allows common themes and patterns that are ingrained in the text to be methodically revealed. This technique makes it possible to find and compile common themes, particularly in the area of supply chain modelling for the construction materials industry. The foundation for a thorough grasp of recurring patterns and trends in the pertinent literature is established by identifying these thematic threads.

3.6.1.2 Content Evaluation

In the process of synthesising data, content evaluation is critical to gleaning important information from selected articles. Using content analysis, a thorough review of the material is conducted to identify important subjects, problems, and difficulties. This process of analysis is essential to promoting a deep understanding of the topic being studied. This method guarantees that the synthesis goes beyond a basic comprehension of the subject matter by exploring the details, which adds to a deeper and perceptive reading of the chosen literature.

3.6.2 Data Analysis

The data analysis stage, which uses methods specific to the type of information at hand, is an essential step in drawing meaningful conclusions from the synthesised data:

3.6.2.1 Qualitative Evaluation

Qualitative data analysis techniques are applied in the analytical stage to extract meaningful information from textual data. In order to reveal the subtleties buried in the literature, this entails a careful analysis and interpretation of recurrent themes and patterns within the text. A thorough grasp of the subject is attained by examining these thematic components, which aids in a detailed and nuanced analysis of the text's content.

3.6.3 Findings and Insights

The results of data synthesis and analysis make a substantial contribution to a better comprehension of the literature by enabling the identification of recurrent themes, obstacles, and variables affecting supply chain modelling. Trends and advancements in the sector are examined through analysis, yielding insightful information. Moreover, the recognition of deficiencies in the current body of literature facilitates recommendations and avenues for enhancement. The complete concepts and findings derived from this exhaustive evaluation of the literature provide a strong basis for further research. One of the most important tasks involved in this is creating a novel supply chain model specifically for the construction materials industry. This study's use of a systematic review technique enhances the research's overall credibility while enhancing the reliability and accuracy of the findings.

3.7 Considerations for Ethical Behaviour

3.7.1 Ethical Foundation

Conducting a comprehensive literature review requires strict adherence to rules and maintenance of ethical norms in order to guarantee the proper and moral use of resources. The review procedure included careful consideration of the following ethical issues:

3.7.1.1 Fair Use and Copyright

It is important to respect the concepts of fair use and copyright, with particular emphasis on utilising and citing copyrighted works within the bounds of fair usage.

3.7.1.2 Attribution and Citation

Strict adherence to proper citation and attribution guidelines guarantees that all sources included in the review are appropriately cited and give credit to the original authors. This method protects writers' intellectual property rights while maintaining academic rigour.

3.7.1.3 Data Privacy and Security

Strong security measures are put in place to guarantee the privacy and confidentiality of sensitive or private data in compliance with current data protection laws and regulations.

3.7.2 Adherence to Research Guidelines

The established research principles, conduct guidelines, and ethical standards are followed in the systematic literature review. A crucial component of the research process is adhering to the guidelines and rules established by respectable institutions and organisations.

3.7.3 Licenses and Permissions

For any content derived from copyrighted works, the required licences and permissions are carefully sought and recorded in order to guarantee adherence to intellectual property rights.

3.7.4 Accountability and Transparency

Transparency in reporting must be upheld at all times during the assessment procedure. The final study findings contain comprehensive documentation and frank disclosure of any ethical difficulties or barriers found throughout the literature assessment.

Research that is both responsible and ethical must start with ethical concerns. By adhering firmly to these ethical norms, this systematic literature review seeks to offer insightful information while maintaining the highest standards of ethical conduct and research integrity.

3.8 Methodology's Limitations

3.8.1 Limitations Overview

As with any research method, it is crucial to acknowledge the inherent limitations of the systematic literature review that was carried out for this study. These restrictions are essential for understanding and assessing the information and findings from the study.

3.8.2 Possibility of Publication Bias

Publication bias may arise since the systematic literature review is dependent on published studies. This suggests that the tendency of academics to publish studies with noteworthy or good results may have an impact on the findings.

3.8.3 Restrictions on Language

Excellent non-English publications may be left out of the review, which is predominantly performed in English. This would reduce the amount of pertinent material from non-English-speaking countries that is included.

3.8.4 Subjectivity in Quality Assessment

Subjectivity in judging the quality of each source may enter the process even in the presence of well specified rules for quality evaluation.

3.8.5 Data Availability

The quality and accessibility of the data in the literature depend on the authors' reporting, which might result in restrictions on the scope of the study because certain sources may contain inaccurate or incomplete data.

3.8.6 Changing Field

Building material supply chain modelling is a dynamic and ever-evolving area. The condition of the field at a particular moment in time is captured by the systematic literature review, which may overlook recently published studies.

3.8.7 Recommendations for Future Research

It is critical to understand that these restrictions are a natural part of the selected methodology and do not lessen the significance of the research findings. Rather, they act as informative markers for regions where further study might expand upon or go beyond these constraints.

3.8.8 Mitigation Techniques

Despite these limitations, a lot of work has gone into minimising biases, maintaining openness, and following best practices while doing a systematic literature review. To reduce the possibility of bias, a methodical and comprehensive approach was used for data collecting, screening, and analysis.

3.8.9 Reporting Transparency

The known limitations are openly addressed in an attempt to maintain the validity and reliability of this study. They are acknowledged for encouraging transparency and honesty in the spirit of responsible research.

These limitations underline the need to proceed with caution when interpreting the results, but they also point to the possibility that these issues might be resolved and that more study could further our understanding of supply chain modelling for construction materials.

Chapter Four: Results Analysis

4.1 Part One: Technologies

there has been an increasing number of technologies in recent years that are specifically designed to improve and optimize supply chain processes. Presented below is a carefully selected compilation of technologies that have recently attracted considerable attention and scrutiny from researchers.

4.1.1 Blockchain

Within the domain of the construction material supply chain, numerous studies have explored the application of blockchain technology. However, these studies exhibit considerable variations in their focal points. This thesis conducts a systematic literature review, delving into four primary papers that offer insights into the potential applications and repercussions of blockchain technology within the architecture, engineering, and construction (AEC) industry.

Initially, the research conducted by Algan TEZEL, Eleni Papadonikolaki, Ibrahim YITMEN, and Per HILLETO(24) in 2020 emphasized the utilization of blockchain as a means to encourage positive industrial practices through incentivization. Conversely, their subsequent work in 2021, alongside Algan Tezel, Ph.D., Pedro Febrero, Eleni Papadonikolaki, Ph.D., and Ibrahim Yitmen, Ph.D.,(25) focused on the necessity of developing global standards for interconnecting diverse blockchain systems. Pankaj Dutta, Tsan-Ming Choi, Surabhi Somani, and Richa Butala(26) offered proposals addressing scalability issues, supply network coordination, and blockchain's application in humanitarian supply chains, Table 4.1 provide summary of the use of blockchain in supply chain. Meanwhile, the work by Haitao Wu, Pan Zhang, Heng Li, Botao Zhong, Ivan W. H. Fung, and Yiu Yin Raymond Lee(27) concentrated specifically on the construction phase of building projects, emphasizing progress payments administration and supplier chain dynamics. These studies underscored two crucial roles of blockchain technology in construction: preserving data integrity and using smart contracts to enhance the effectiveness and reliability of business operations.

The divergent outcomes of these studies can be attributed to several factors: variations in study scope, distinct challenges and opportunities inherent in the construction sector, disparities in data sources, sample sizes, and research methodologies. Additionally, the authors' professional experiences, specialized knowledge, and individual perspectives may have influenced their inclination to prioritize specific facets of blockchain technology within building supply chains.

All studies emphasize the necessity of reinventing current business structures, roles, and strategies to fully leverage the potential of blockchain technology. Blockchain introduces novel paradigms, highlighting the imperative for adaptability and creativity to harness its inherent benefits.

Furthermore, the collaboration and exchange of information within AEC supply chains are on the brink of a significant transformation facilitated by blockchain technology. Its utilization cultivates enhanced trust among stakeholders and ensures intellectual property protection.

In conclusion, while these papers unanimously highlight the transformative potential of blockchain in AEC supply chains, their diverse emphases and recommendations contribute to a comprehensive understanding of the technology's implications. These findings underscore the ongoing need for research, adaptation, and education to fully realize blockchain's potential in the construction sector. As the industry evolves and embraces technological advancements, blockchain stands poised to enhance transparency, collaboration, and efficiency in supply chain management. Nevertheless, addressing barriers, establishing global standards, fostering innovation, and regulating the technology are essential for a successful transition. The strategic implementation of blockchain solutions presents opportunities for sustainable practices, improved coordination, and incentivizing best industry practices in the construction sector.

Functional aspects of SC	Details
Supply chain resilience	- Reduces the impacts of disruptions by applying "preventive and proactive" measures for risk management and providing multilayer protection for SC network - The structural design of blockchain helps capture both the organizational and network risks
Supply chain provenance	- Helps in granular provenance of physical products, which are produced and transported in complex, inter-organizational, or internationally spanning SCs - Provides certifiability, traceability, verifiability and tractability of the product information
Supply chain reengineering	- Enhances the transparency and visibility of SC and enables process automation - Eeliminates intermediaries and enables real time tracking through traceability, privacy and data management techniques
Security enhancement	- Enables authentication, confidentiality, privacy and access control of data, and integrity assurance in the services - Integrating with IoT and RFID, blockchain helps in enhancing security, consensus mechanism for dynamic data storage, transparency and data protection, reliability and cost management
Business process management	- Enables efficient business process management through smart contracting by compiling the control flow and business logic of interorganizational business processes - Effectively used for asset management and customer-order-process management which improves the efficiency, traceability and visibility of orders
Product management	- Improves cycle time, productivity and quality, and enables product differentiation through its integration with SCs. - Helps in product deletion and price tracking during the product distribution in the end to end SCs

Table 4.1:Blockchain for major supply chain functions[26]

4.1.2 BIM

Building Information Modelling (BIM) is a revolutionary tool in the fast-paced world of construction. A digital paradigm called Building Information Modelling BIM offers a breakthrough approach to project development by integrating the complex web of functional and physical components of structures. This technology appears as a pillar in the continuous digital transformation, changing the way experts think through, organise, and carry out building projects. Throughout the construction lifecycle, BIM fosters efficiency and precision by providing a full, visual, and simulatable representation of architectural plans. As such, it has become a vital tool.

4.1.2.1 BIM- WMS

In a 2019 study conducted by Po-Han Chen and Thanh Chuong Nguye,[10] the potential synergy between Building Information Modelling (BIM) and Web Map Service (WMS) in the construction industry's supply chain management was examined. This synergy signifies that their integration holds promise in enhancing various facets of supply chain operations. The study particularly highlights the importance of developing a BIM-WMS plug-in as a supporting tool for logistics and supply chain management (Figure 3.1,3.2). This plug-in enables the comparison of diverse materials and suppliers, facilitating informed decision-making during supplier and material selection phases (Figure 4.3, 4.4).

Moreover, the study suggests that as more material and supplier information is incorporated into the system and as other BIM and WMS software are integrated, the tool's convenience and utility will expand. This indicates its adaptability and scalability to accommodate additional data and resources. Notably, the tool's capacity to maximize BIM information in construction projects is emphasized, especially in integrating various transportation means through platforms like Google Maps. This underscores its potential for extending beyond supplier and material selection to encompass transportation selection.

However, from my perspective, despite the highlighted potential advantages of integrating BIM and WMS, certain challenges need acknowledgment. These include integration difficulties, the critical requirement for accurate data, and the limited transportation modes and software covered in the plug-in (Autodesk Revit and Google Maps). Further study and real-life case analyses are imperative to understand the potential benefits comprehensively. Presently, the tool's applicability is limited to smaller-scale projects, thus rendering it less advantageous and impractical for larger construction endeavours. Addressing these limitations through extensive study and practical application is necessary to fully comprehend and leverage its benefits in larger-scale construction projects.

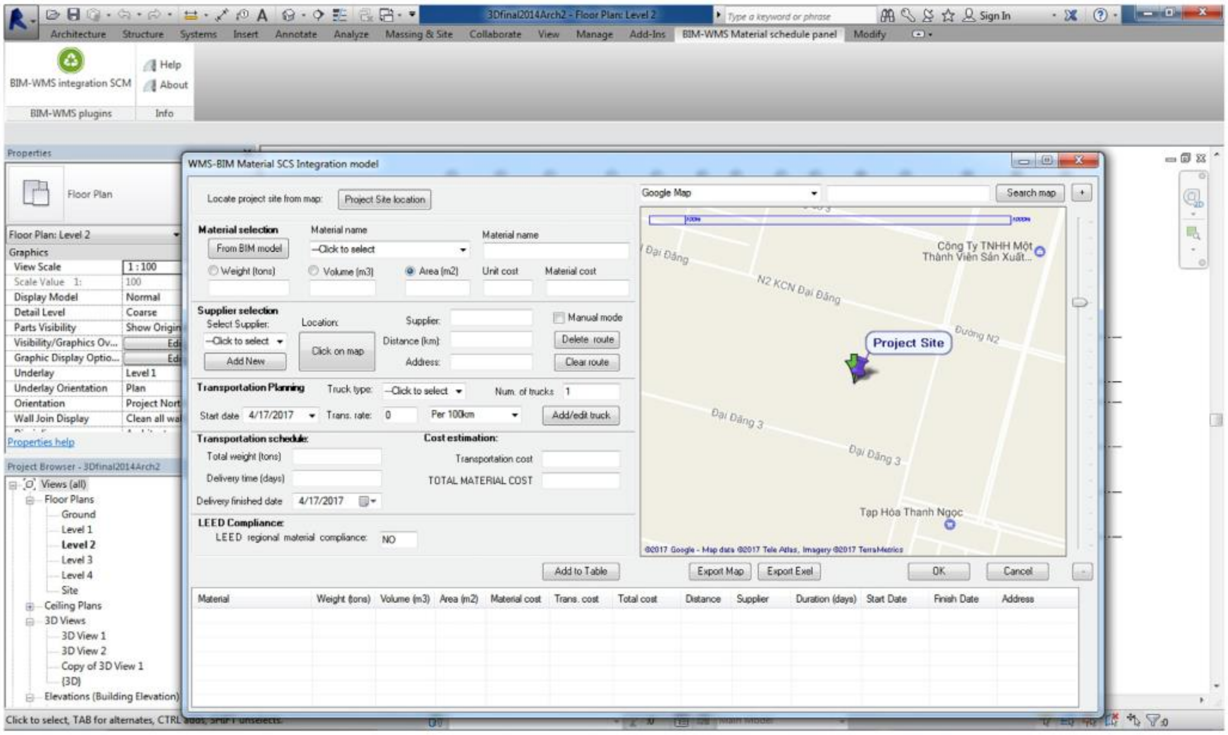

Figure 4. 1: User Interface of the BIM-WMS plugin(10)

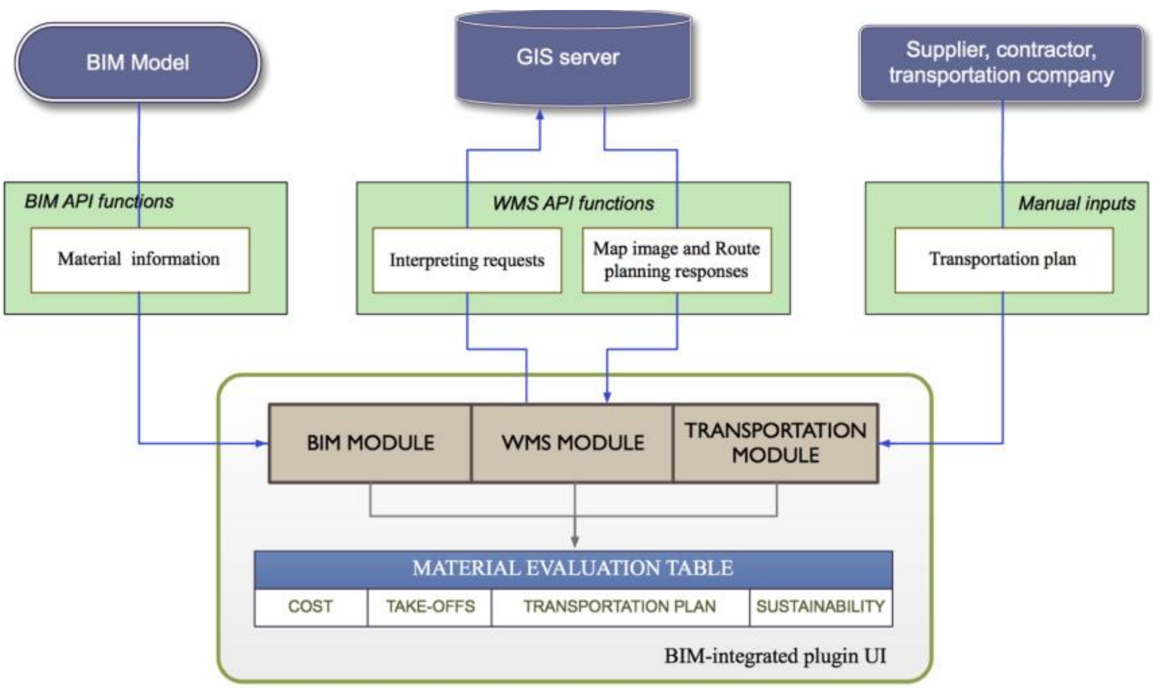

Figure 4. 2: Flow of information exchange in the BIM-WMS integration model.(10)

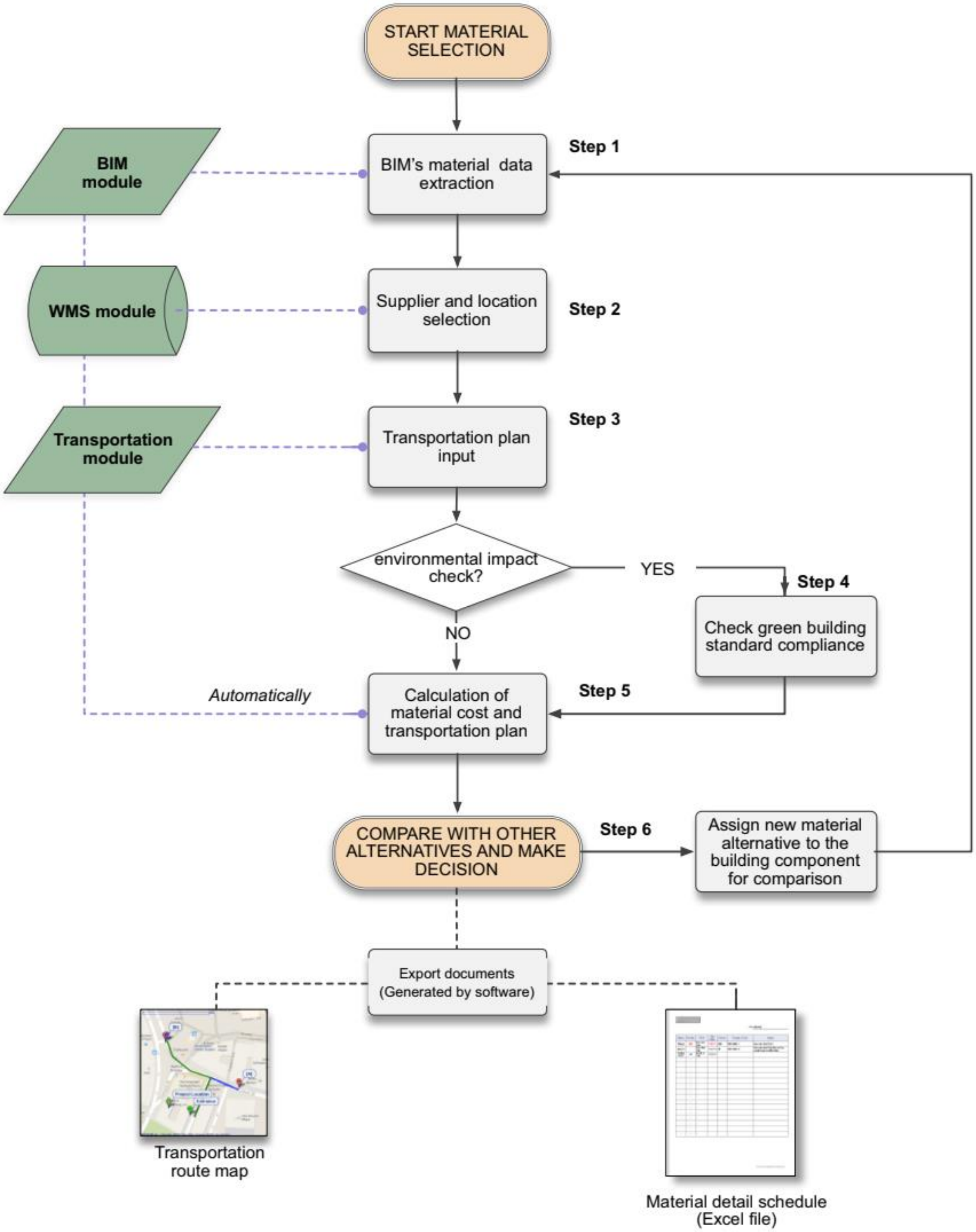

Figure 4. 3: Material selection process using the BIM-WMS plugin.(10)

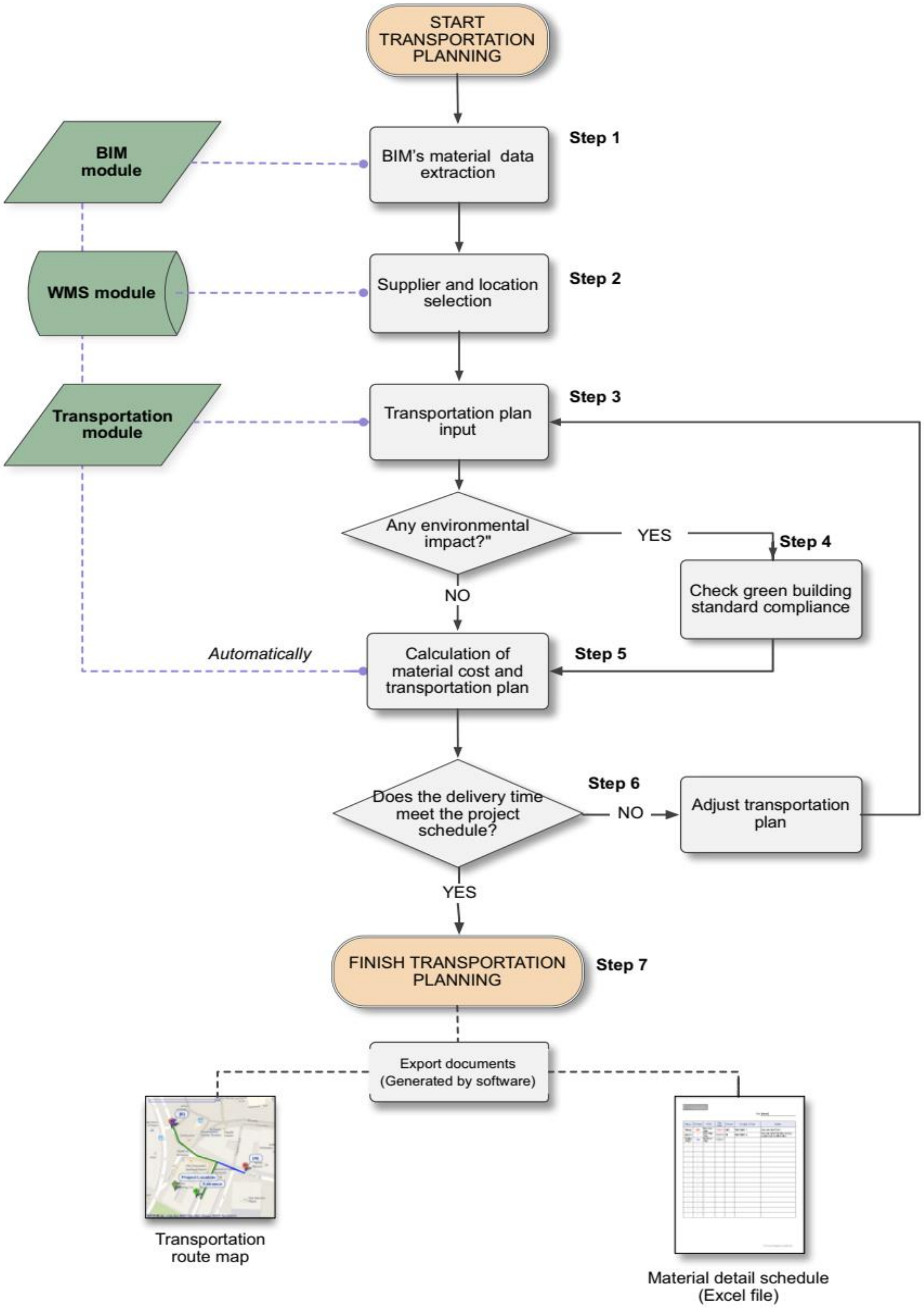

Figure 4. 4: Optimization of the transportation plan using the BIM-WMS plugin to meet the project schedule.(10)

4.1.2.2 BIM and GIS

A 2022 study conducted by Syed Uzairuddin and Mohit Jaiswal[28] delved into the integration of Building Information Modelling (BIM) and Geographic Information Systems (GIS) in the construction materials supply chain (Figure 4.5). This integration facilitates the categorization of building elements based on their supply chain attributes, distinguishing between Engineer to Order (ETO), Make to Order (MTO), Assemble to Order (ATO), and Make to Stock (MTS) products. This categorization offers valuable insights into the unique characteristics of each element, their interconnections, and logical combinations within the supply chain.

Additionally, the study found that the integration of BIM and GIS provides a comprehensive approach that enhances logistics, improves supply chain visibility, and enables real-time tracking of material statuses. Furthermore, manufacturers are now providing BIM models with detailed parameters and specifications included in the metadata. These enhanced models enable more accurate representations of building products and contribute to improved tracking of as-built information.

Although the integration of BIM and GIS in the construction material supply chain shows promise, organizations must address several challenges to maximize its benefits. These challenges encompass data management, the intricacies of supply chains, tracking resources in a dynamic environment, adjusting activity schedules, adopting new technologies, ensuring data accuracy, and staff training. Despite these challenges, the concept remains highly encouraging and warrants further expansion and in-depth study in the future. Continued exploration and research can provide insights to optimize this integrated model for enhanced efficiency and effectiveness in the construction material supply chain.

Figure 4. 5: The GIS module's input parameters and their sequence.[28]

4.1.2.3 4D BIM- GIS

In 2019, a study conducted by Yichuan Deng, Vincent J. L. Gan, Moumita Das, Jack C. P. Cheng, and Chimay Anumba, F.ASCE[(29)] successfully integrated 4D Building Information Modelling (BIM) and Geographic Information System (GIS) for supply chain management in the construction industry. This integration demonstrated the framework's potential in enhancing decision-making processes within construction supply chains (Figure 4.6). The research notably accentuated the intricacies involved in selecting material suppliers, emphasizing that relying solely on unit prices and delivery distances is inadequate. To make optimal supplier choices, the combined impact of these factors must be carefully considered.

Furthermore, the study presented mathematical methods for optimizing the number of deliveries, a factor significantly influencing the overall cost of the supply chain. Such optimization becomes pivotal for cost efficiency in construction projects. Additionally, the paper illustrated that the allocation of consolidation centers should be based on criteria such as cost and location. This efficient allocation can result in cost reductions associated with inventory management and material deliveries.

From my perspective, while this study provides a promising solution for supplier selection, delivery optimization, and consolidation center allocation, there are several challenges that need addressing. These challenges pertain to the complexity inherent in making these decisions and the multitude of variables influencing them. Additionally, a weakness observed in this study is its limitation of consolidation centers to serve one project at a time. This limitation could deter decision-makers from utilizing this solution when dealing with multiple projects simultaneously, utilizing the same centers. This limitation serves as a basis for future research and warrants further exploration in subsequent studies.

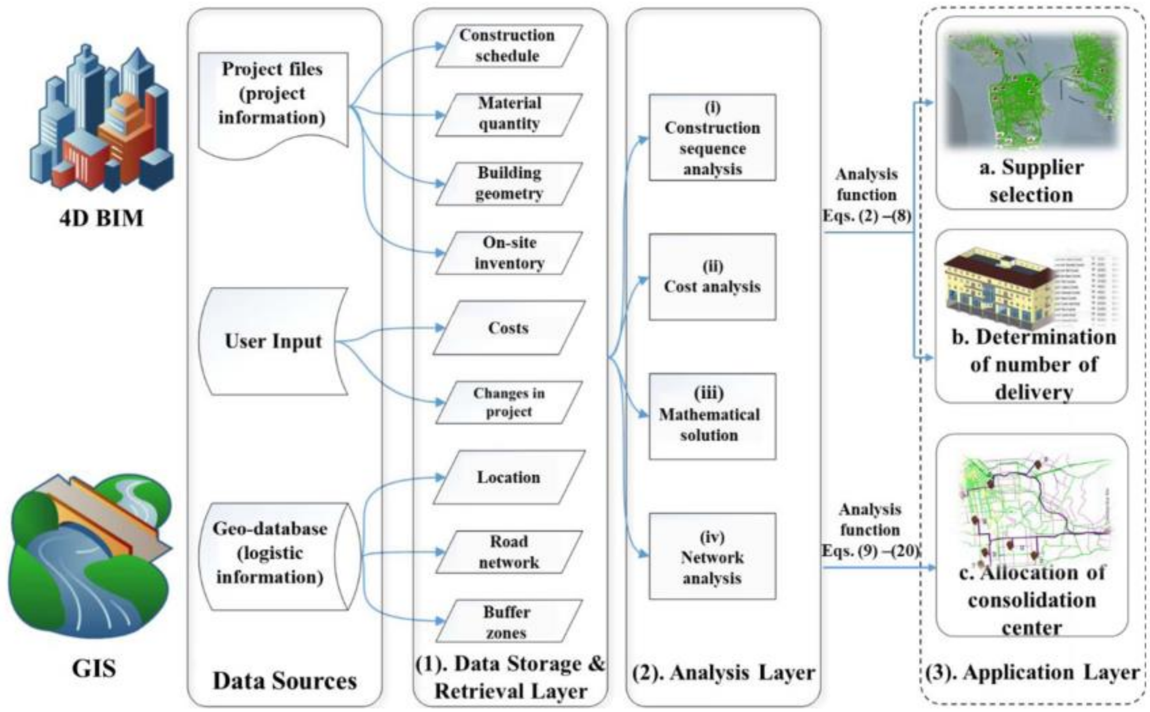

Figure 4. 6: Framework overview(29)

4.1.2.4 BIM-RFID

In 2020, Qian Chen, Bryan T. Adey, Carl Haas, and Daniel M. Hall[30] conducted a study exploring the integration of Building Information Modelling (BIM), Radio-Frequency Identification (RFID) technology, and Look-Ahead Plans (LAP) in the construction material supply chain (Figure 4.7). Through simulations, the study showcased the potential of this integrated workflow to significantly enhance construction processes and decision-making. The integration of BIM-RFID-LAP, demonstrated via simulations, resulted in a notable 16.1% reduction in the time required to construct a single floor. This reduction underscores the potential for substantial gains in construction efficiency.

Furthermore, the workflow promotes the digitalization of the construction material supply chain by enabling the exchange of material and lead time information through a central database and Dynamo scripts. This digitalization streamlines communication and information sharing, reducing reliance on conventional methods like 2D drawings, PDF documents, and emails. Detailed look-ahead plans integrated into the workflow facilitate more accurate and reliable decision-making regarding material flow processes. This synchronization of site progress with material delivery status enhances decision-making and coordination.

Moreover, the workflow incorporates change request feedback sub-processes, fostering early collaboration between suppliers and contractors. This collaborative approach minimizes rework and contributes to reduced construction time by avoiding fragmented decision-making. Integration of modules into related sub-processes within the workflow eliminates complex coordination issues. A unified material coding system enhances information exchange efficiency, while a central database automates sub-processes, thereby improving information visibility and collaborative decision-making.

Although demonstrated in a specific project example, the study highlights the proposed workflow's high level of customization and adaptability to various construction projects of different scales and types.

From my perspective, I concur that the use of RFID in the construction material supply chain has transformative potential in material tracking and management, augmenting transparency and efficiency in the construction process. RFID tags affixed to materials and equipment enable real-time tracking of their location, movement, and status throughout the supply chain, leading to improved inventory management, reduced errors, and enhanced communication among stakeholders.

However, it's crucial to address challenges associated with implementing RFID technology in the construction material supply chain, such as data standardization, interoperability, and resistance to change, to fully capitalize on its benefits. Additionally, a notable weakness in this study lies in its reliance on simulated scenarios, highlighting the necessity for real-world site testing to validate the findings. Future research endeavours should explore the applicability and

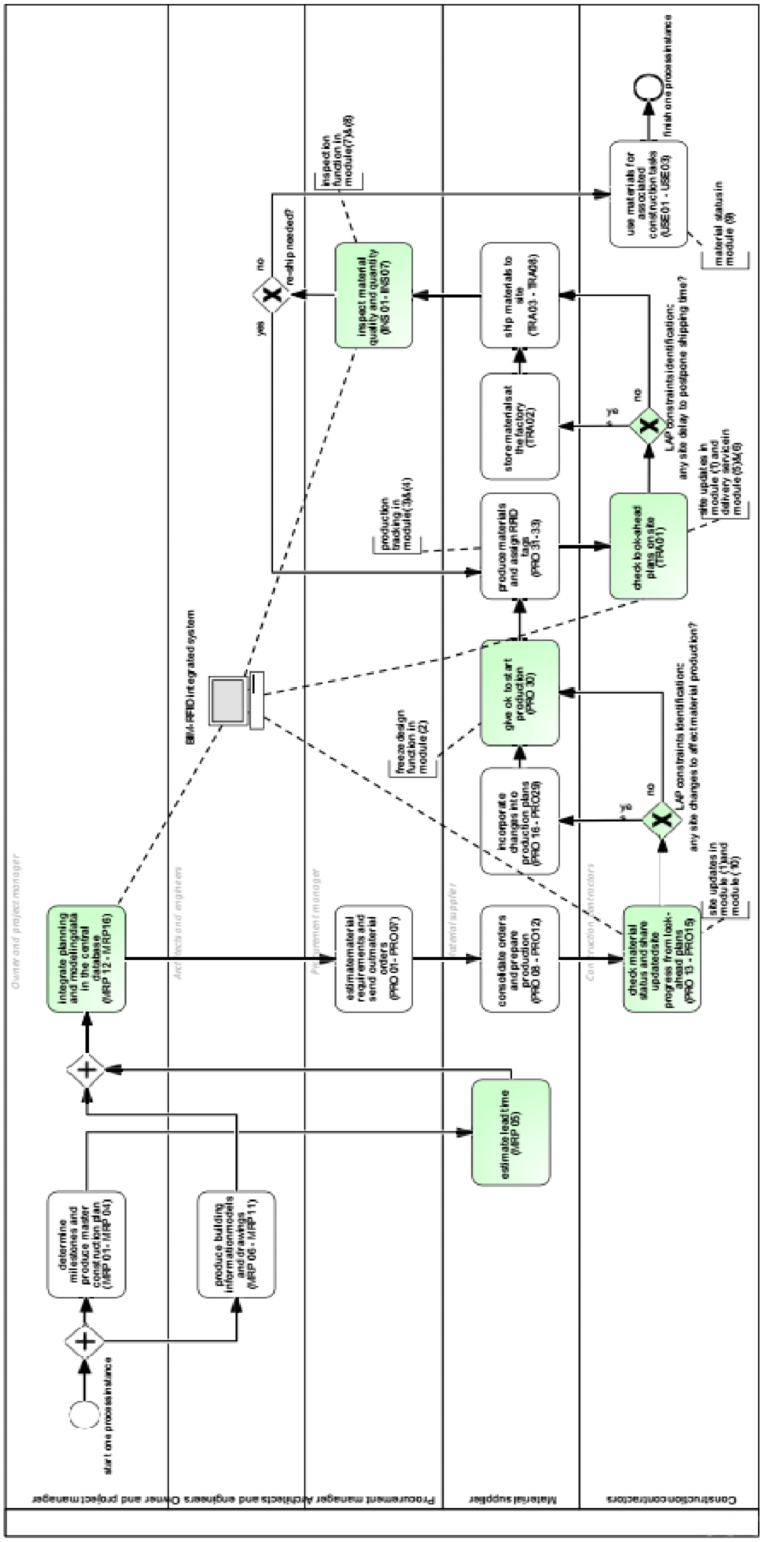

Figure 4. 7: BIM-RFID-LAP workflow at a high level of abstraction[30]

of this integrated approach in diverse construction projects, considering factors like data ownership and legal aspects related to Industry 4.0 technologies.

4.1.2.5 BIM and Lean construction practices

In 2020, Martin Evans and Peter Farrell[31] conducted a comprehensive study on Lean Construction within the context of supply chain management for construction materials in Jordan. This study delved deeply into the perspectives, obstacles, and potential advantages recognized by three key stakeholder groups in the Jordanian construction sector: owners, consultants, and contractors.

The research paper unveiled a consistent viewpoint among these major stakeholder groups concerning the barriers hindering the adoption of lean construction principles. This consensus highlighted common challenges that must be addressed to facilitate the acceptance of lean practices. The study pinpointed specific hurdles acknowledged across these groups, notably encompassing insufficient support and commitment from top management, inadequate worker training, and a deficiency in awareness and knowledge about lean construction.

Moreover, a pivotal discovery emphasized the imperative need for a cultural shift within the Jordanian construction industry to enable the implementation of lean practices. This shift revolves around issues relating to training, awareness, and engagement of all stakeholders. The paper also offered valuable recommendations to bolster the adoption of lean construction in Jordan. These recommendations included increased management involvement, advocacy for lean education and awareness, improved worker training, and fostering collaboration and trust among stakeholders.

Despite their differing roles and objectives, the study suggested the potential for future collaboration among the three stakeholder groups. Such collaboration could reap benefits for the construction industry by promoting the shared adoption of lean principles. Additionally, the study identified areas for further research, such as exploring specific lean tools or techniques, utilizing interviews and case studies for comprehensive analysis, and validating the model through confirmatory factor analysis.

The study's findings are promising, acknowledging that lean construction is a transformative approach within the construction industry, aiming to boost efficiency, diminish waste, and enhance overall project outcomes. Given these reasons, the investigation of the link between BIM and lean construction becomes imperative, aligning with the current global trend. Despite numerous challenges highlighted in this study, it emphasizes the importance of further exploration in this area. Future research should endeavour to surmount these obstacles and extend the study to other countries and diverse-scale projects, thereby expanding knowledge in this field.

4.1.3 AI

In 2021, Kuang-Sheng Liu and Ming-Hung Lin(32) conducted a comprehensive study exploring the utilization of AI technology and its diverse applications within the supply chain of the construction industry. (Table 4.2) The study emphasized the pivotal role of digital transformation in supply chain management, stressing the necessity of establishing resilient and international supply chains to meet the demands of a globalized industry. Furthermore, it highlighted AI's contribution to enhancing the efficiency of sustainable supply chain management in construction materials.

The implementation of AI technology assists in discerning varying levels of efficiency among different enterprises, thereby identifying areas requiring improvement. The study emphasized the significance of collaboration with suppliers for sustainable supply chain management, emphasizing the importance of aligning interests and fostering synergistic effects to promote sustainable practices and operational efficiency. Additionally, despite potential upfront costs, the integration of AI and sustainability measures is shown to contribute to long-term economic benefits, including improved corporate image, product competitiveness, and overall economic performance.

From my perspective, while the findings of this study regarding the construction materials industry in Taiwan are valuable, their direct applicability to diverse industries or regions might be limited. The impact of AI on supply chain management can vary based on industry-specific characteristics. Moreover, the study's focus on 12 enterprises in Taiwan's construction materials sector raises concerns regarding the generalizability of findings. A broader and more diverse sample is essential to provide comprehensive insights into AI's applications within this field. Thus, considering the broader context of the construction materials sector is crucial when interpreting the outcomes of this study.

Supplier Management	Artificial Intelligence Supply Chain Management
Aiming at single supplier	Aiming at several suppliers in the supply chain
Mid-term commitment	Long-term commitment
Medium communication	High communication
Middle manager	Top manager
Pure trading, slightly involving in strategies	Strategies applied to all parts, allies
Not necessarily building criteria for suppliers	Stressing on process management
Concentrating on suppliers' capability	Paying attention to the integration of entire supply chain system

Table 4. 2:Difference between supplier management and artificial intelligence supply chain management.[32]

4.1.4 LINGO 14.0 Optimization Modelling Software

In 2018, Piotr Jaśkowski, Anna Sobotka, and Agata Czarnigowska[33] conducted an in-depth study on implementing a model to tackle supply chain challenges. The model's optimized solution notably reduced on-site storage space to a mere 400 m^2. Additionally, materials stored in off-site locations (covering an area of 280 m^2) were delivered at specific intervals, significantly enhancing material storage efficiency and delivery processes.

Furthermore, the system incorporates fuzzy figures for material prices, allowing for unpredictable price fluctuations. Under various scenarios—optimistic, moderate, and pessimistic—the fuzzy numbers technique showcased superiority over deterministic models, showcasing its applicability in real-world scenarios with unpredictable pricing.

The study strongly emphasizes that efficient supply chain planning in construction projects, while considering unpredictable material prices and accommodating material substitutions, can substantially decrease inventory costs. The model offers practical and pragmatic strategies for determining optimal supply routes, quantities, and required storage spaces.

However, the study highlights the necessity for further refinement of the model to encompass other uncertainties, such as variations in supplier capacity and demand fluctuations. This extension would result in a more comprehensive tool for managing supply chains in the construction domain.

From my perspective, this model presents significant potential despite persisting challenges. The acquisition of precise data for material prices and supply channels poses resource-intensive demands. While adept at handling price uncertainties, the model's inability to explicitly address common construction uncertainties, particularly buffer stock uncertainty, remains a notable limitation.

Nonetheless, utilizing LINGO 14.0, this decision model offers pragmatic solutions for the supply of construction materials. While effectively tackling price uncertainties, its limitations in addressing various construction uncertainties underscore the need for continued refinement. Despite these challenges, it stands as a valuable resource for enhancing supply chain management within construction projects.

4.1.5 GAMS software and Cplex solver

In 2020, Ali Reza Hoseini, Siamak Noori, and Seyed Farid Ghannadpour(34) explored the GAMS (General Algebraic Modelling System) software and Cplex solver for complex optimization problems in construction material supply chain management, (Figure 4.8) shows the different internal and external causes of problems. Their study introduced a two-objective mathematical model, considering cost and pollution, demonstrating distinctive outcomes compared to previous models and revealing substantial improvements. Incorporating varied costs in supplier selection significantly influenced decisions, enhancing precision by integrating multiple cost factors. The research detailed how the Pareto boundary forms through epsilon values, offering visual depictions illustrating supplier choices' impact on pollution, costs, and economic conditions. Economic shifts remarkably affected supplier selection, underscoring the dynamic nature of supply chains. Additionally, the study emphasized the importance of sustainability in supplier selection, advocating for its integration into future studies for promoting eco-friendly practices in construction supply chains. Recommendations were made to augment the mathematical model, including incorporating more objective functions and addressing uncertainties, shared vehicle use, diverse pollution types, and external disruptive elements like economic and political crises.

From my perspective, while the study illuminates the challenges of complex models reliant on specialized tools like GAMS and Cplex solver, it also enriches supply chain management by elevating the consideration of pollution, economic conditions, and sustainability. Despite the hurdles, these advancements in understanding further underline the significance of optimizing green construction supply chains. This emphasis on environmental impact and cost efficiency heralds a path for future advancements in sustainable construction practices.

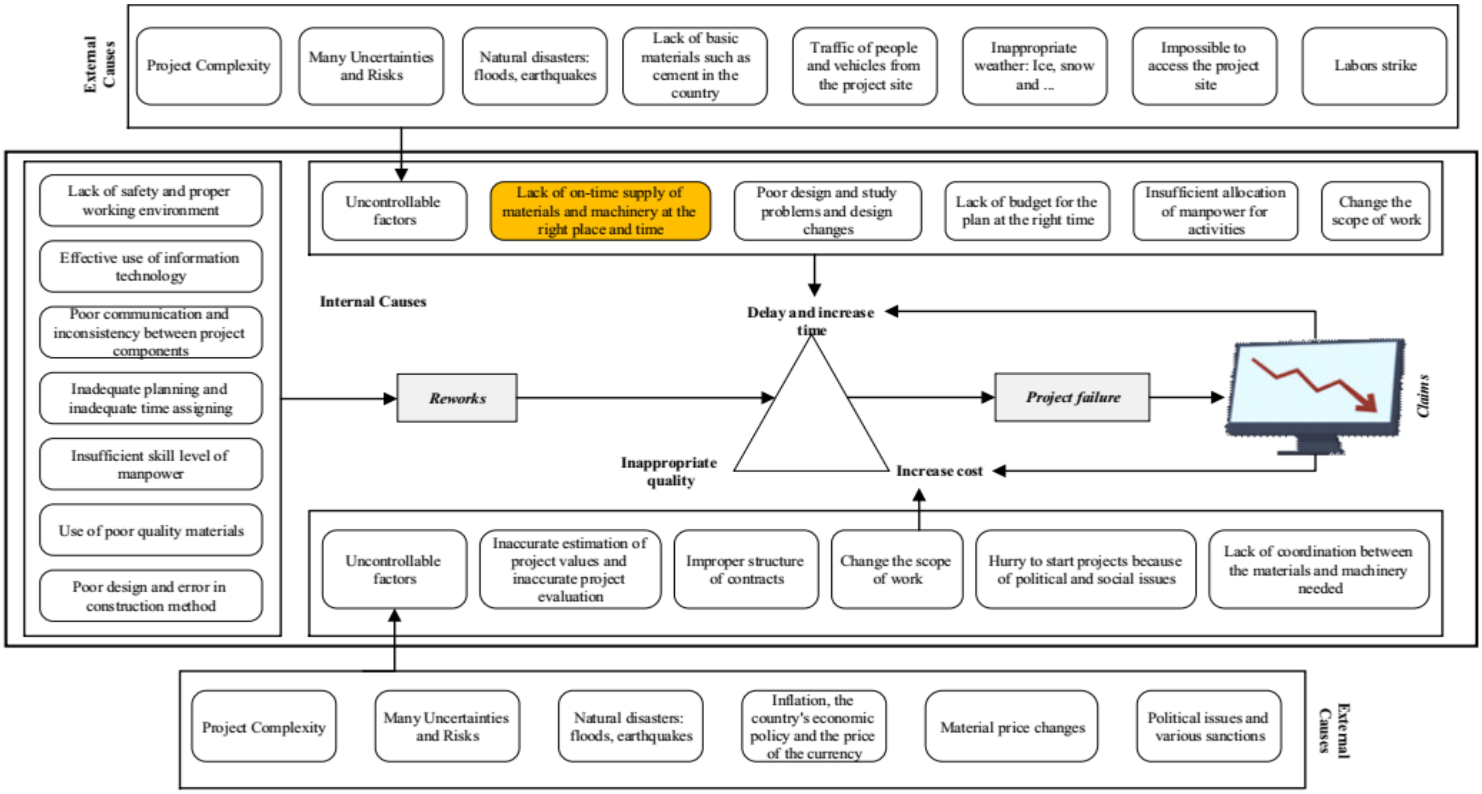

Figure 4. 8: The internal and external causes of project failure.[34]

4.1.6 Cloud manufacturing and internet of things, Augmented reality, Smart tracking sensors and Big data and analytics Cloud Manufacturing and IoT

In 2019, a study conducted by Andrea Patrucco, Federica Ciccullo, and Margherita Pero[35] delved into the transformative influence of advanced technologies, including Cloud Manufacturing, IoT, Augmented Reality, Smart Tracking Sensors, and Big Data Analytics on the management of materials in construction supply chains (Table 4.3) shows the main classes of I4.0 technologies and related benefits. The research revealed significant impacts of "Augmented Reality" and "Smart Tracking Sensors" on organizational dynamics, necessitating skill development through training initiatives to manage these tools effectively. Moreover, "Big Data Analytics" and "Cloud Manufacturing and IoT" introduced new roles, albeit with a more limited organizational impact, primarily supporting back-office data analysis or specific activities. The study emphasized the pivotal role of external stakeholders, including suppliers, in evaluating and adopting these technologies, underscoring the necessity to consider their perspectives and demands. Human adaptation and skill development emerged as pivotal factors determining the success of technology-driven Business Process Reengineering (BPR) projects. Collaborative perspectives in BPR involving stakeholders from diverse organizational levels were deemed crucial to surmount resistance to technological change. The study highlighted the significance of assessing I4.0 projects from both practical, short-term perspectives of involved actors and the long-term outlook of management, considering the speed and risks associated with new technological assimilation.

The study uncovers vital insights into integrating I4.0 technologies in construction supply chains. It aligns with my viewpoint by accentuating the organizational and process impacts of these technologies. While acknowledging their transformative potential, it brings attention to substantial challenges. The shift towards a technology-centric culture and the need for comprehensive organizational transformation pose significant hurdles. Despite these challenges, the paper underscores the substantial promise of I4.0 technologies, offering concrete benefits such as process improvement, issue resolution, and skill development. Overall, the study advocates for a comprehensive approach that acknowledges both the advancements and hurdles in implementing I4.0 technologies in construction supply chains.

	Definition	Main benefits
Cloud manufacturing and internet of things	Cloud manufacturing is the process of utilizing well-established manufacturing resources, such as enterprise resource planning (ERP) through the cloud. By this way, the information can be viewed, updated and applied at any time or place. It can take many different forms such as cloud computing, virtualization and the internet of things	Support real-time data collection about production and inventory levels, which not only allows the supply chain to act in a predictive manner to the challenges of a volatile market but also helps in the improvement of operational performance through effective management of production activities
Augmented reality	Interactive experience of a real-world environment where the objects that reside in the manufacturing system are "augmented" by computer-generated perceptual information in order to simulate future events	Supports a reduction in excess product that quickly loses value, faster response to changing client requests or supplier availability and better optimization of shipments and the assurance of complete deliveries
Smart tracking sensors	Sensors with intelligence capabilities to enable information processing, communication and self-adaptation functions	Supports traceability of each item and generation of highly visible supply chains where the location of all the elements could be ascertained at any point in time
Big data and analytics	The use of machine learning and artificial intelligence techniques to process and extract information from diverse datasets for prediction and modeling	Support of machine-enabled decisions with minimum human intervention thus improving the timing and the depth of these decisions

Table 4. 3: Main classes of I4.0 technologies and related benefits[35]

4.2 Part Two: Methodologies

4.2.1 System Dynamics (Simulation technique)

In 2021, Mary Bajomo, Akinola Ogbeyemi, and Wenjun Zhang(2) conducted a comprehensive exploration into the utilization of System Dynamics (SD) in managing material procurement for the Engineering, Procurement, and Construction (EPC) industry. Their study extensively showcased how System Dynamics modelling effectively captures and simulates the intricate dynamics of the Construction Material Supply Chain (CMSC). One of the paramount aspects highlighted in their study was the pivotal role of information sharing within the CMSC. They emphasized that effective information exchange among CMSC units is a linchpin for optimizing procurement processes and ensuring the seamless flow of materials.

Moreover, the study shed light on the significance of maintaining appropriate safety stock levels within the CMSC. It underscored that having the right level of safety stock is imperative for mitigating uncertainties and disruptions in the supply chain. Additionally, the research revealed the complex interrelationship between supplier policies and CMSC performance. Supplier safety stock and service levels emerged as critical factors contributing to the overall robustness of the supply chain.

From my perspective, while System Dynamics proves to be a potent approach for modelling and managing intricate supply chain systems, as highlighted in this study regarding material procurement in the EPC industry, it also underscores the importance of addressing challenges associated with model construction, validation, managing uncertainties, and the inherent complexity of the model. The study exemplifies the benefits of System Dynamics while emphasizing the need to navigate and overcome these challenges to maximize its effectiveness in managing material procurement within the EPC industry.

4.2.2 Robust Optimization (RO) model

In 2019, Pei-Yuan Hsua, Marco Aurisicchioa, and Panagiotis Angeloudisb[36] conducted a detailed investigation into the application of the Robust Optimization (RO) model within modular construction supply chain management. Their findings highlighted the model's remarkable performance, surpassing the 2SP (Two-Stage Stochastic Programming) model across a majority of demand profiles. This superiority underscores the RO model's adeptness in navigating uncertainties and fostering cost efficiency, aligning perfectly with a risk-averse approach.

Furthermore, the RO model's proficiency in minimizing cost variances was observed, significantly reducing the likelihood of straying from anticipated total costs. This aligns seamlessly with risk-averse strategies, prioritizing the mitigation of financial risk. Notably, the study shed light on the pivotal role of warehouse location selection in influencing the probability of delivery delays and overall construction efficiency. The research underscored the advantages of reducing the distance between the warehouse and the construction site for timely material deliveries.

Emphasizing the significance of optimal manufacturing duration, the study highlighted the delicate balance required between production rates and variable production costs. Extended production timespans were identified as potential culprits leading to unmet demands and increased project extension costs.

Moreover, the RO model's unique capability to illuminate inventory variations throughout the entire supply chain proved invaluable. This clarity empowered effective management of production buffers and resource allocation, a pivotal aspect in optimizing resource and capital allocation strategies. The model's adaptable structure renders it versatile for diverse modular construction projects, with its capacity to accommodate various settings with minimal alterations.

Despite challenges such as model complexity and data requirements, the RO model's potential to fine-tune resource allocation and spearhead cost-efficient, risk-averse strategies in the modular construction supply chain is undeniable.

In my perspective, even though there are some difficulties with the model being complex and needing specific data, the RO model is excellent at organizing how we use our resources and making smart, cost-saving plans in the construction supply chain.

4.2.3 SmartPLS, Bootstrapping. and importance-Performance Map Analysis (IPMA)

In 2021, the study conducted by Temidayo Oluwasola Osunsanmi et al[37]. utilized sophisticated statistical methodologies such as SmartPLS, Bootstrapping, and Importance-Performance Map Analysis (IPMA) to delve deeper into the factors critical for attaining supply chain resilience in construction. The investigation revealed that Construction 4.0 technologies—embracing robotics, cloud computing, and 3D printing—significantly bolster the Construction Supply Chain's (CSC) resilience, akin to a "vaccine" during challenging pandemic periods (Table 4.4). Furthermore, the research pinpointed collaboration among supply chain partners as a pivotal determinant for CSC resilience, accentuating the significance of factors like partnership, resource sharing, and information alignment. Additionally, the study emphasized the indispensable role of integration strategies encompassing financial transparency, early supplier involvement, and coordinated planning to fortify CSC resilience. The findings further highlighted the imperative nature of lean supply chain structures in reducing wastage, consequently enhancing the CSC's resilience. Notably, while Construction 4.0 technologies stood out as highly essential and effective, collaboration, integration, and supply chain structure were also deemed significant, albeit perceived as less critical, especially concerning the supply chain structure.

From my perspective, considering the challenges related to variable selection and addressing multicollinearity for refining model accuracy, this research presents invaluable insights into leveraging advanced technologies and fostering strategic collaborations to reinforce the construction supply chain. It highlights not only the immense potential but also the intricacies involved in crafting precise models to achieve resilience, thereby offering a guiding path for future advancements and innovations in the industry.

Characteristics	Meaning
Visibility	The ability of a construction stakeholders to identify the location of their inventory easily
Agility	The ability of a construction stakeholder to deliver with short lead times
Flexibility	The willingness of a construction stakeholder to respond promptly to change in construction design
Sustainability	The supply chain ability to reduce the waste on the environment
Redundancy creation	The ability of CSC to hold extra inventory and maintain low capacity utilisation without affecting the overall performance of the supply chain
Risk management	The features or principles set in place by construction stakeholders to eliminate uncertainties within the chain
Velocity and speed	The ability of CSC member to finish a task as soon as possible
Revenue sharing	The sharing of revenue and returns effectively among CSC members effectively
Adaptability	The ability of CSC to respond to the changes outside the supply chain
Sensitivity	The ability of CSC to automatically monitor the activities within the chain

Table 4. 4 Characteristics of a resilient construction supply chain[37]

Chapter Five

5.1 Conclusion

This systematic literature study thoroughly investigated the integration of technology in the construction industry's supply chain. The synthesis of a wide range of academic research has shed light on how these technologies are changing the landscape. The studied literature highlights the revolutionary potential of technologies such as advanced data analysis and Internet of Things (IoT) applications, including Building Information Modelling (BIM), in optimising supply chain operations. The themes that have been discovered, including better decision-making, real-time visibility, and more communication, highlight the complex effects of technology adoption.

As indicated in the literature, a number of criteria, including stakeholder participation, organisational preparation, and technology infrastructure, are necessary for the effective adoption of these technologies. Furthermore, issues like standardisation, data security, and the necessity for qualified workers have become recurring topics. In order for practitioners and policymakers to fully utilise technology interventions in the building supply chain, they must acknowledge these complications.

5.2 Implications and Recommendations

The review's conclusions have important implications for the academic community as well as business. Researchers can expand upon the gaps and issues indicated for additional inquiry, while practitioners can use the findings to influence strategic decisions regarding technology adoption. To address data security problems, recommendations include the creation of standardised frameworks, industry professional training programmes, and cooperative activities.

5.3 Future Studies

Even though this analysis offers a thorough summary, there are still interesting directions for further investigation. Initially, comprehensive case studies exploring into the real-world obstacles and successes of integrating technology in certain building projects would provide insightful information. Furthermore, there is a great chance to learn more about how cutting-edge technologies like blockchain and artificial intelligence could affect the building supply chain. Prospective investigations have to concentrate on creating prescriptive models for surpassing implementation obstacles and developing an innovative culture in the building sector.

Finally, this comprehensive assessment of the literature improves our knowledge of the complex interactions between technology and the building supply chain. Through acknowledging the obstacles and possibilities present in this intersection, scholars and professionals alike may play a part in the continuous development of this important sector.

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