POLITECNICO DI TORINO

Corso di Laurea Magistrale in Ingegneria Gestionale

Percorso Logistica

Tesi di Laurea di II livello

Improving the supply chain of building materials

Supervisor: Prof. Giovanni Zenezini

Candidate: Paolo Pitruzzello

Academic Year 2022-2023

Abstract

Scope and Objectives

The purpose of this dissertation is to conduct a literature review in the field of the construction industry with regard to the sustainable management of materials and processes.

A literature review will identify existing research, studies and information relating to inefficiencies in the construction industry. It will also provide an understanding of what has been studied, where there are gaps in current knowledge and what contributions could be made in this area. There can be an assessment of the methodology, the validity of the findings and the relevance of previous research to the current state of the construction industry.

The construction industry is vital to economic growth and infrastructure development. By investigating the inefficiencies within the industry, it is possible to address a pressing issue that affects multiple sectors.

As a first step, the "Scopus" database was used to identify academic articles on the subject, using the keywords: "supply chain management", "construction industry" and "sustainability". This search produced a total of 60 results. These results underwent an initial analysis in which abstracts that were not directly relevant to the topic were excluded. As the articles were thoroughly reviewed, it became apparent that certain citations were repeated, although they had not been included in the initial selection. As a result, these additional articles were deemed relevant and were subsequently included in the scope of the research. This iterative refinement of the selection process allowed for a more comprehensive and refined exploration of the topic.

Upon initial scrutiny of the 30 selected articles that caught my attention, facilitated by their abstracts, a recognisable narrative began to take shape. Within the construction sector, a landscape of inefficiency came into focus, revealing an area that had barely scratched the surface of the potential benefits offered by research and technology over the last few decades. This initial exploration highlighted the pronounced gap between the current state of the industry and the advances that research and technology could potentially bring.

One of the fundamental pillars of the analysis was (Maria Ghufran 1, 2022), which I used as a framework for my researches and analyses. This article provides a comprehensive review and analysis of system dynamics in the context of the construction industry (CI). It substantiates the notion that a holistic perspective is imperative, given the vast scale and multifaceted nature of the construction industry. By delving into the intricate interplay of its various components, the research highlights the importance of assessing the impact of hypothetical solutions or strategies on the system as a whole. By scrutinizing system dynamics, the research not only reinforces the importance of acknowledging the holistic nature of the construction industry but also illuminates the inadequacies of localized interventions.

Through a comprehensive review it has also been possible to identify the key areas that hold the potential for the introduction and implementation of approaches aimed at optimising the overall efficiency of the industry, while at the same time reducing its environmental footprint. This analysis was conducted with a particular focus on aligning strategies with the principles of a circular economy.

These areas included sustainable material sourcing, efficient waste management, new approaches in the management of CI (construction industry) projects and innovative construction techniques.

The literature review highlighted ways in which circular economy principles could be integrated, enabling the industry not only to improve operational efficiency but also to make meaningful progress towards sustainability.

The disparities uncovered in my analysis are closely aligned with the findings of a study conducted by (Agarwal, 2016), who proposed a shift to a digital construction organization by exploiting and combining existing technologies such as rapid digital mapping, BIM, digital collaboration, internet of things, and future proof design and construction.

1 Introduction

1.1 Introduction to construction industry

The construction industry plays a critical role in the economic development of many countries, providing employment opportunities and infrastructure that support social and economic activities. Despite its importance, the construction industry faces numerous challenges that hinder its progress and growth. These challenges range from technological limitations to financial constraints, and they have a significant impact on the industry's productivity, efficiency, and sustainability.

The construction industry is the world's largest user of natural resources; in the past it has utilized a non-sustainable linear economic model based on the "take, make, dispose of" concept and continues to do the same: a circular economy (CE) approach has become essential to make this industry sustainable over time.

By implementing CE principles in CI, industry costs would be lowered, negative environmental impacts reduced, inherent complexities tackled, and resilience of urban areas enhanced to make them more liveable, productive, and convenient.

The goal of the CE is to promote new and creative approaches in industries and infrastructure, to drive economic growth, develop cities and communities that can be sustained over time, address the challenges of climate change, and reduce the negative impact of materials.

These priorities are in line with the United Nations Sustainable Development Goals (UNSDGs), which were established in 2015 following the Millennium Development Goals (MDGs). The UNSDGs aims to safeguard the environment, eliminate poverty, and guarantee that all individuals have access to peace and prosperity by 2030.

To delve into such a complex industry is essential to have an overall view of the mechanism and all the stakeholders involved; since focusing on a specific topic can lead to misleading results and may suggest improvements that have negative impacts on a broadscale. This requires the identification of the key enablers of the CE, which lead towards sustainable development in the CI, and the understanding of how they are related to each other, in order to better evaluate the impact of a choice in one specific area to the overall efficiency of the entire supply chain.

To achieve this starting point and have a clear vision of the main topics, we can exploit the results of (Maria Ghufran 1, 2022) in the article "Circular Economy in the Construction Industry: A Step towards Sustainable Development". As mentioned in the introduction, this article has been used as a key to the reading.

It guides us on a complete overview of the CI, using a system dynamics approach (SD): a methodology for understanding, modelling, and analysing complex systems over time. This is a way of thinking about systems that emphasizes the interrelationships and feedback loops among different components of a system. By using SD, it is possible to understand the trade-offs and be conscious of the variable that can be used as catalyser to trigger chain mechanisms.

After a literature review based on 35 research articles published from 2010 and onwards, the researchers came up with 31 enablers of CE in CI. The literature revies was followed by a survey with pioneers in the field. Then, the team used the Cronbach value, a statistical measurement that determines how closely related a set of variables or items are as a group, to finally get to 10 indicators.

A high value of Cronbach's alpha indicates that the items in a scale or test are consistent and reliable in measuring the construct or dimension of interest: a commonly accepted threshold for acceptable reliability is a Cronbach's alpha value of 0.70 or higher; they obtained a value of 0.91 meaning that the set was statistically significant.

The final list of enablers they obtained was:

- Government financial support

- Extension of product life cycle
- Organizational incentive schemes
- Innovative and smart technologies
- Strict regulations
- Policy support
- Awareness through workshops and education programs
- Resource durability
- Political priority
- Material circularity

After identifying the key enablers, a Casual loop diagram CLD was used to represent graphically the results.
Given a data set of variables, CLD represents variables as node and the relationship between them as arrows. These relationships can be positive or negative, indicating the direction and strength of the effect one variable has on another.

The software used to reach this purpose was Vensim, a tool for modelling and simulating dynamic systems. It is commonly used in the fields of systems thinking, system dynamics and business modelling; as it is designed to help users build models that represent complex systems such as: supply chains, energy systems, and economic markets.

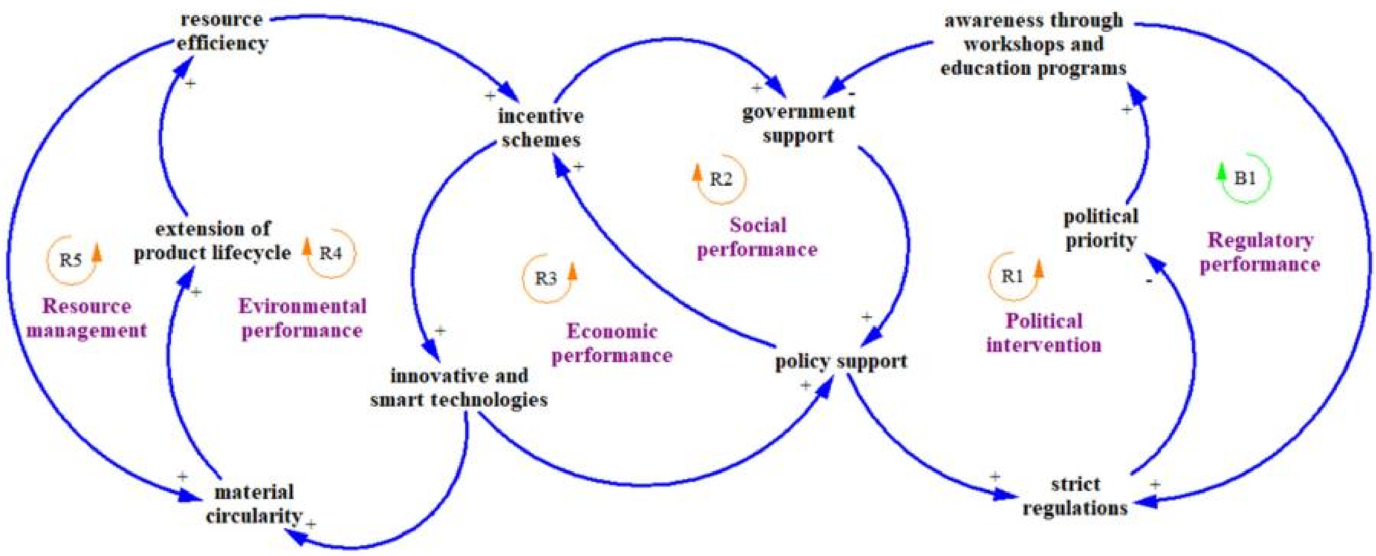


Figure 1.1 "Casual Loop Diagram" (Maria Ghufran 1, 2022)

The diagram depicted in **Figure 1.1** is the output of the software used that schematises the relationships between variables.

With its expressive ability to show the complex environmental, technological, and political mechanisms and how they are interrelated, the diagram provides a very interesting overview.

Narrowing down the scope of the analysis and focusing on just a few aspects, we can identify the so called "feedback loops ", which are localised chain mechanism that group together a subset of variables and attempt to explain a micro-phenomenon within the complex situation of the global ecosystem. These feedback loops are important to determine what the variables are and what the strategies could be in the different areas: political, regulatory, economic, and technological.

Within the different loops there are what can be considered to be the sub-objectives for the achievement of the main goal, such as Resource

Management, Policy Interventions, Legislation and Standards, Environmental, Economic and Social Performance.

Analysing the positive vicious circle within the feedback loops is essential to have a clear situation of the behaviour and responses of the external stakeholder in the short terms; allowing the firms to make tactical decisions that take into account the cross-cutting effects.

The main chain mechanisms described by (Maria Ghufran 1, 2022) are the following:

- The implementation of strict regulations could imply a lack of interest for some political parties in strengthening those regulations, due to which public awareness would also be decreased.
- A decrease in awareness can be solved through workshops and education programs, this will lead to the need for increased government financial support.
- An increase in government financial support can lead to an increase in policy support, which helps to achieve organizational incentive schemes.
- Better organizational incentive schemes lead to an increase in innovative and smart technology adoption.
- An increase in the adoption of innovative and smart technologies can lead to material circularity, due to which there will be an increase in the product life cycle.

From the point above, is it possible to infer that policy and governmental support play a crucial role in creating an environment that encourages businesses and industries to adopt circular practices. This can be achieved through the implementation of policies and regulations that incentivise sustainable practices and provide a framework for businesses to operate within.

The implementation of strict regulations is also critical in the absence of an accurate assessment tool capable of evaluating the performance of the supply chain and determining the risks and environmental and social impacts. It is therefore essential that regulatory and incentive tools go hand in hand with the technical ability to quantify impacts and have deterministic estimates on a set of KPI's tailored to the particular case.

The technological aspect also plays a key role in the implementation of circular economy practices in the CI, since this sector uses standards and techniques that have developed much more slowly than in other high-tech industries.

The nature of the construction industry has historically been highly localised and only few companies had the necessary funds to exploit new techniques and achieving economies of scale. Innovations in this sector are essential to achieve a leap in efficiency and to explore breakthrough solutions to reach results in reducing the environmental footprint, promoting material circularity, and increasing the product life cycle. Therefore, political, and governmental support is needed to bridge this gap and to provide incentives for companies that are active in this field.

All these aspects and barriers that interfere with the adoption of CE in CI, will be further analysed in the next chapters by reviewing the literature in order to find solutions and alternatives.

1.2. Project Management & Logistics Factors, with focus on JIT

From a logistics point of view, the construction industry is considered to be among the least efficient. As reported by (Thomas, 2005) in England it is the least efficient industry overall.

Analysing the reasons behind these inefficiencies is essential to comprehend the nature of such an industry and to open a field of research aimed at improving operational and management activities.

In agreement with (Heaton1, et al., 2022), the main factors behind this weakness are:

- Complexity
- Material flow
- Lack of information sharing

By complexity is meant the qualitative characteristic of a system, defined as an organic and structured aggregate of interacting parts, that causes it to take on properties that are not derived from the simple interplay of them. In the case of groups working, the efforts of each party to collaborate, cooperate, and compete will also have a significant impact that could be unpredictable.

Typically, the complexity of a project depends on the complexity of the elements of which it is composed, the number of agents involved, the number of interactions, and the complexity of the interactions themselves.

In the construction of an infrastructure, the stakeholders involved are the client, the site manager, the architects, the engineers, the workers, the various suppliers, and the community near the site where the work is to be done. While the main elements can be seen as different lifecycle phases as Concept, Development, Design, Construction, Commission, Operation, and Decommissioning.

One of the main mistakes that is made is to think that these phases are consequential and independent of each other, as in reality the phases are partially overlapping and a change in the design phase can have major repercussions on the construction or material supply phase. This is another indication of complexity, such as the presence of feedback loops, social dynamics, and the health of the system reacting to an event or any other change.

Conceiving the complexity is also useful for defining the risk profile and thus assessing in advance costs due to unexpected events and delivery delays. This aspect may be solved through the utilisation of solution like the ones described in **Chapter 3**.

In the early design phase, complexity risk is driven from interfaces with external stakeholders and the obligation to comply with laws and regulatory decrees. In the Construction phase, complexity risk is driven from the large number of tasks, the size of the project, peak effort levels, the size of the project team, complex supply chains, access, logistics, progressive staging. (Heaton1, et al., 2022)

Additionally, there is the technical complexity that comes from the fact that each project has unique characteristics that need to be addressed with techniques and solutions tailored to the specific circumstance. For each small task a standard technique can be used within a range of choices, but on a global level each project requires an ad hoc solution, so it becomes necessary to have professionals with high experience in the field.

Complexity has also a human component; in fact, the aspects of leadership and soft skills within a large team should not be underestimated. The ability of a worker in this field must be evaluated not only as an individual actor but also as the ability to work in group, knowing how to create synergies among the actors involved.

According to Matthew Winchur, an expert in property, construction, and civil sectors, these are the five drivers when choosing an approach for managing complexity across an enterprise:

1. Existing expertise in complexity management.
2. Bureaucracy layers and decision making.
3. Maturity of systems and procedures.
4. Function of the Project Management Office
5. Commercial profile of projects

The first point refers to the level of risk management maturity present within the company and how easily unexpected events are handled. The second to the level of formality required to make a decision effective. Indeed, the bureaucracy within a company should be flexible enough to allow the players involved to make decisions and take actions to facilitate the smooth flow of activities during a project; but not so flexible that it could impacts the company's performance at a broader level than the perimeter under the control of the employee.

The third driver, again according to Matthew Winchur, refers to the level of business process integration and its robustness in ensuring project workflow. This aspect is considered in the literature to be one of the main weaknesses of the system, which is why great emphasis is placed on BIM software. Which can guarantee a better flow in the workflow of projects within the CI framework, as will be explained later in **Chapter 3.2.**

The presence or absence of a project management office is another important variable in defining the risk profile. The functions of this organ can vary among companies. In some places they have a support function to facilitate the tracking of activities and provide status updates. In other contexts, this office performs a more directive function, in which it assigns SLAs (service level agreements) and defines expected turnaround times.

The fifth and final driver, on the other hand, refers to the risk aversion of the business area.

Today, with the advent of globalisation and the network economy, the success of logistics is based on the ability to achieve a greater degree of integration between the company and the various players involved in the "extended" production chain (external supply chain). (Heaton1, et al., 2022)

Effective material flow is one of the most significant factors in the construction industry, and unfortunately has many issues and flaws. Material flow refers to the movement of materials to the construction site in the right quantities, at the right time and without interruptions in quality or timing. Deviating from these quality criteria and standards has the effect of increasing costs and wastages.

In order to correctly design or reorganise the distribution network, it is necessary to start not only from a precise definition of the service level, but also from a precise mapping of the flows, by identifying the number, functions and role of the logistics hubs and the main sources and destinations of goods.

The logistical layout of this industry is what is known as a 'fixed layout', where the production of a single unit of product takes place. This means that all machinery, equipment and resources generally move to this location to complete the working cycle and programme.

This type of layout is usually used for large products such as ships and aircraft. However, in the case of the construction industry, there is an additional detail that makes supply chain management even more complex, namely that the physical location where work is carried out changes from project to project and it is not possible to predict in the long term where the next construction sites will be. (Heaton1, et al., 2022)

This feature brings a number of additional difficulties, such as the need to redesign and reorganise the movement of materials and vehicles, and the need to review the road infrastructure from time to time. Geographical analysis may also be required to analyse the characteristics of the terrain, given the size of the machines and trucks used to sort and deliver materials.

Large construction projects may even require new roads to create suitable conditions for receiving trucks.

These are just a few of the reasons that are in the way of the achieving learning economies. Another one is that a particular supplier of raw materials that worked well in previous projects may not be the best choice in a different context, since there are different routes to be travelled and therefore also different supply times. This also means less involvement of external suppliers and less consolidation of external relationships, which can further increase procurement costs.

These difficulties can be overcome by implementing high-tech solutions such as the BIM-WMS integration (Po-Han Chen, 2019) and the BIM-GIS one (Syed Uzairuddin ⇑, 2022) mentioned in **Chapter 3.2.3.**

In fact, looking at things from a higher and aggregated point of view, makes it possible both to manage transport resources optimally and to make ideal routing decisions, selecting the most suitable alternative according to the conditions of the specific case.

The integration of these systems also has a strong environmental impact, since optimising the management of transport and warehouse resources corresponds to a reduction in the carbon footprint.

Due to the implicit logistical nature of the construction industry, the need for technological implementations to reduce transport costs and emissions is increasingly necessary, as large amounts of material have to be transported to the site, which has a major impact on transport costs and, more generally, on storage, handling, inventory and management costs.

Almost all regional construction projects have specific materials management issues, including preparation and scheduling of supplies, procurement, use, storage, surplus and waste management. The main activities responsible for these issues of improper material flow on site are loading and unloading of construction materials, transporting materials to and from the site, bricklaying, cement storage and tile cutting.

Proper materials handling is critical because materials can account for 50%–60% of a project’s cost; (Heaton1, et al., 2022) propose an interesting solution to solve this debate: careful selection of suppliers and the presence of a construction consolidation centre (CCC).

"Construction Consolidation Center" is a facility involved in streamlining and centralizing certain aspects of the construction process; involving the coordination of materials, equipment, labour and information related to different construction projects to enhance efficiency and reduce costs.

This approach underlines the need for a systematic framework that not only optimizes costs but also streamlines the logistics associated with materials procurement and distribution. By strategically partnering with suppliers and establishing a CCC, construction projects could potentially benefit from enhanced efficiency, reduced costs, and minimized delays attributed to materials-related challenges.

The procurement of suppliers should be done through criteria that maximise innovation, learning economies and workload management efficiency to match capacity. Incentive schemes should also be in place to maximise their involvement in achieving common goals. In supply chain management in general, alignment of objectives is indeed a key factor in eliminating information asymmetries and making the parties involved strive for the overall optimum rather than trying to maximise their short-term profit.

To have up-to-date and accurate data on which to evaluate suppliers, the use of digital technologies to track materials is essential. One of the earliest approaches dates back to 1987, when barcodes were introduced to scan materials into their physical locations; subsequently, the limitations of these technologies were overtaken by radio frequency identification (RFID) technologies, which enabled the identification and real time tracking of products without the need to individually scan the various loading units.

Building a database with this information is indispensable for evaluating suppliers and choosing those that minimise late deliveries, which are considered to be one the most important causes of supply flow disruption.

In addition, clear and specific communication between contractors and suppliers could ensure readily available stock of products, especially for materials with longer lead times, where variability and unexpected events have a greater impact.

Supplier selection also plays a key role in achieving environmental sustainability, as "a company is not more sustainable than its supply chain". (Krause, 2009)

Clearly defining and understanding who the stakeholders are directly involved in a particular area, function, or phase of a project within an organisation is paramount to the roles and responsibilities of the stakeholders themselves, who must interpret the corporate strategy and translate it into their respective areas of responsibility.

In construction projects, there are 3 key roles that drive the dynamics of construction of a work. The construction manager is directly responsible for the project itself; the commercial director is responsible for the supply of materials and legal contracts that ensure that quality and delivery requirements are guaranteed; and finally, the cost planner, who makes decisions to ensure that technical requirements are in line with budget constraints.

It will therefore be the responsibility of the commercial manager to evaluate the selection of suppliers according to their sustainability rating, and of the construction manager and cost planner to select the technological solutions to be implemented in a new project.

The topic of supplier selection is discussed in more detail later in **Chapter 4**.

1.3. Research scope, objectives and methodology

Another interesting consideration is implementing JIT logic in an Engineering to Order (ETO) industry such as construction. The benefits of JIT inventory management have been widely studied in the supply chain literature, as it can eliminate excess inventory and overstocking.

The JIT model reduces the costs of procuring, managing, and storing excess raw materials and inventory, resulting in a higher rate of stock turnover, which prevents stock from being left in your warehouse for too long and becoming obsolete. This last aspect has a different impact in the construction industry than in other sectors, such as the food industry, where the turnover rate is crucial due to the extreme speed with which food perishes. However, overstocking of materials such as cement and bricks results in high capital commitment, which can destabilise a company's financial position and liquidity.

Sustainability has taken on a growing significance within various industrial sectors, particularly in the realm of supply chains. The primary objective behind sustainable supply chain initiatives is to craft products or items using methods that are energy-efficient, resource-conscious, and socially responsible. Moving forward, customer satisfaction will hinge not solely on the product itself, but also on the incorporation of socially and environmentally responsible practices, as well as economically efficient manufacturing concepts.

In the Engineer-to-Order (ETO) industry each product is nearly one-of-a-kind and tailor-made to meet specific customer demands. ETO supply chains in the construction industry consider three different macro-phases: engineering, manufacturing and on-site installation. Traditionally, these ETO projects have suffered from a lack of synchronization across these three phases, leading to budget overruns. The main underlying issue stems from the insufficient integration of information flow between the different phases. (Patrick Dallasega, 2017)

Changes occurring on the shop floor or during installation at the designated site often do not automatically trigger corresponding updates to project planning, scheduling, and engineering processes. Hence, there exists a pressing need to address and bridge this synchronisation gap between the realms of engineering, manufacturing, and field installation. The objective is to foster effective and sustainable supply chain management, characterized by minimized inventory levels and the timely, just-in-time (JIT) delivery of materials and information.

During the engineering phase, which precedes the commencement of a typical Engineer-to-Order (ETO) project, the primary concept, requirements, and technical specifications are determined by the customer or architect. Subsequently, an internal project manager formulates the master plan, typically presented in the form of a macro-Gantt chart. This comprehensive plan delineates the contents of work packages, the durations of various phases, milestones, and sets the project's deadline, all based on the aforementioned specifications.

This is followed by an approval phase where a more detailed 2D and 3D model is reviewed and ratified. Once the make-or-buy decision-making process reaches completion and the shop floor designs are ready, they are transmitted to the production planning department.

Then, the logistics department organizes the transport and supply of the necessary components to the construction site, and finally the installation foreman defines, together with project management, the installation schedule.

As emphasized in this thesis, the construction industry faces a notable shortfall in effectively managing its supply chains compared to other sectors. This disparity is primarily attributable to significantly extended supplier lead times, which frequently exceed the predictability of on-site work completion. Consequently, achieving Just-in-Time (JIT) delivery of Engineer-to-Order (ETO) components from the factory to the construction site poses a challenging task. (Patrick Dallasega, 2017)

This suggests that we should then shift the focus to other factors such as the management of C&D wastes and the introduction of BIM.

2.0 Circular Economy

2.1 Definition of Circular Economy

Over the last century, there has been a linear relationship between economic growth and resource consumption: raw materials are extracted from nature and transformed into finished products; during this transformation process, fuels are consumed and a certain amount of emissions are generated.

The increased demand for finished products has been accompanied by an increase in the number of raw materials that need to be extracted. At the end of their lifecycle, most waste products are expected to end up incinerated or sent to large open landfills. (Kaza S, 2018)

Reversing this trend requires an approach in which resources have a purpose after they have been discarded from a previous application, and therefore no new raw materials need to be extracted to make new products. This is the concept known as the 'circular economy'.

The EU parliament defines the Circular Economy as "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended."

It is a paradigm shift from the traditional linear economic model of "take-make-consume-throw away", in which the material at the end of their purpose has zero residual value. The old system had led to resources and products losses along the value chain, and most of all has created a system in which primary resources are needed in a rapidly and progressive way, almost as fast as wastes are produced.

In order to understand how to implement a CE approach, it is crucial to understand the main reasons behind the linear model; one of them is the low level of commodity prices relative to labour costs. In addition, it was cheaper to use new primary resources than to recycle, as the cost of recycling involves additional processing.

Another factor justifying the linear model is availability, sometimes there may not be enough recycled materials available to meet the demand, furthermore new resources may also offer better quality and might be more suitable for industrial purposes; that is why Quality Assessment (QA) holds a significant part in Selective Demolition (**Chapter 2.2**).

In addition, some regulations may require the use of new primary resources for certain products or industries due to health or safety concerns.

Nowadays, the scarcity of resources and rising prices are causing a change of direction, as they are weakening the main reason for the linear economy, so finding a way to reduce the aforementioned strengths could be an interesting strategy.

For example, wider use of selective demolition in CI could address the availability and quality of recycled materials, especially if carried out by independent companies able to achieve economies of scale and develop new technologies and standards. This would also introduce a CE approach that limits environmental impact.

Overall, the circular economy can be seen as a concept that encompasses several strategies focused on minimising, reusing, and recycling materials and resources. CE studies also serve to identify and quantify the circularity gap, i.e., the amount of resources that are wasted because they cannot be returned to the market as inputs. Quantifying this gap makes it possible to assess how far an industry is from achieving a closed-loop system of production and consumption, which would be the theoretical ideal with maximum efficiency. (Thomas B. Christensen, 2022)

In the CI, the assessment of the circularity gap is a complex task due to the long life of buildings and infrastructure, which causes a delay between inflow and outflow, as well as the perishability of the recycled material, which can affect the quality assessment.

There are two more concept related to Circular Economy that deserves to be mentioned: eco efficiency and eco effectiveness. They are two approaches quite different from each other; eco efficiency is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution.

In practice it translates into:

- An increase in resource productivity.
- Reduced material intensity of goods or services.
- Reduced energy intensity of goods or services.
- Reduced dispersion of toxic materials.
- Increased use of renewable resources.

Eco effectiveness on the other hand, goes beyond eco-efficiency in abolishing the very idea of waste, since it aims at maintaining material's status as resources; in the same ways as an approach Cradle to Cradl (C2C).

C2C is based on the idea that "waste = food," and aims to create a circular economy where everything is a resource for something else; to achieve these materials in products should be kept clean and separated, or there should be a system in place to separate them after the item is discarded.

The ISO 14045 standard defines eco-efficiency as "an aspect of sustainability that relates the environmental performance of a product system to its product system value". These efficiency measures can therefore be defined as the relationship between the value created and the cost in terms of resource use or impact caused.

To sum up the difference between these two terms we can quote Michael Braungart in Ellen MacArthur Foundation, in which he describes the difference between eco-effectiveness and eco-efficiency as "Rather than using eco-efficiency to try and minimise material flows, eco-effectiveness transforms products and related material flows to support a workable relationship between ecological systems and economic growth. Instead of reducing or delaying the cradle-to-grave flow of materials, eco-effectiveness creates metabolisms where materials are used over and over again at a high level of quality."

Given the high environmental impact of the construction industry, due to the large amount of materials and resources used, it is essential to analyse the circularity gap to address research areas focused on optimising and reducing it.

Most EU countries have met the 2020 recovery target in the waste framework directive for 70% recovery of CDW; however, the high recovery rates are achieved primarily through backfilling in which valuable materials are crushed and used ad filling materials in, for example, road construction. (Thomas B. Christensen, 2022).

Environmental impact should be assessed using Life Cycle Assessment (LCA), as the creation of value or function of products has an impact on the environment not only during the production or use of the product, but also during the production and distribution phases. Furthermore, LCA provides a proven methodology with a consistent framework of impact categories to quantify and compare contributions to all these impacts in a quantitative way.

As companies see environmental performance as an important competitive advantage, offering better functionality with less environmental impact, the criteria for product eco-labels need to be regularly reviewed and tightened to ensure that they remain available to only a small fraction of the products on the market; because only strict rules on the use of eco-labels can reassure people that there is an environmental effort behind the overpricing. (Hauschild, 2015)

In conclusion, the construction sector's significant generation of end-of-life waste, coupled with a reuse rate of only 20 to 30 percent due to inadequate disassembly-oriented design, underlines the urgent need for change. With a growing population placing greater demands on infrastructure, the need to adopt circular economy methods in the construction industry is crucial.

2.2 Reverse logistic

Managing product lifecycles has become an essential aspect of business in today's globalised and interconnected world. While the traditional supply chain focuses on the flow of products from manufacturers to end users, the concept of reverse logistics deals with the movement of products in the opposite direction. Reverse logistics encompasses the processes involved in handling returned, damaged or obsolete products and ensuring their proper disposal.

With reference to construction industries, reverse logistics (RL) is defined as: "the reverse flow of forward logistics, that steer the construction industry to adopt a closed-loop supply chain, enabling a paradigm shift towards a circular economy" (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021).

Reverse logistics recognises that the life cycle of a product does not end with its sale or consumption; instead, it recognises that attention and management are required even after products have reached their purpose. With the increasing negative impact on sustainability, the Reverse Logistics Supply Chain (RLSC) has emerged as one of the remedies in the construction industry.

Lower quality of recycled materials is one of the most significant barriers in the implementation of CE practices in CI, as structural stability imposes safety standards that reject materials below a minimum quality threshold. It is essential to guarantee the quality of products at the end of their life cycle in order to put them back on the market as primary products and as components of new infrastructure.

The performance criterion of reverse logistics is precisely the quality of the recycled materials compared to the corresponding virgin materials. To produce end products of a quality that meets the expectations of the end user, a Quality Assurance (QA) process-centred and planned approach plays a vital role. This may be related to the fact that demolition activities are often brutal and lack an organically structured process for the conservation of materials.

This helps us to understand why an implementation of RL that focuses on the demolition process is essential. Each task should be carried out with a view to preserving the structural integrity of the components in the best possible way. (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021).

In contrast to other industries, the RLSC in the construction sector is made up of several organisations with different interests, which are responsible for different RL practices. RLSCs in CI operational stages consist of dismantling, on-site processing, off-site resource recovery, landfilling and marketing of reprocessed products. Generally, demolition contractors dismantle, collect, sort and transport recyclable waste to off-site recovery facilities and contaminated waste to landfill. Afterward, they are engaged in reprocessing and marketing products that are still valuable to the secondary market through their own transfer stations and material recovery facilities (MRFs).

The adoption and diffusion of reverse logistics cannot take place without the support of stakeholders. Once again, this case study has to be analysed in the context of a broader picture and the key remains the system dynamics approach of (Maria Ghufran 1, 2022).

Indeed, the scope of the challenge extends beyond the mere optimization of construction and demolition waste management. It necessitates the creation of an intricate logistical network involving multiple actors, underscored by the establishment of a robust market for recycled building materials. This comprehensive approach not only addresses the challenge at hand but also presents a viable solution to the underlying problem of sustainable resource utilization.

Once again, it becomes essential to take into account not only the upstream and downstream links in the supply chain, but also the influence of stakeholders. All the organisation's activities in an RLSC are influenced by four types of external stakeholders: customers (i.e., end users), suppliers, competitors and government, and they can all have potential impacts on the firm’s strategy in terms of RLSC.

In agreement with (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021), there is a gap in the literature for which no one has yet laid a theoretical foundation to fully understand the dynamic social and political context behind reverse logistics in the disposal and remediation of construction and demolition waste.

At the moment, however, our main focus is on the systematic exploration of different solutions and the careful analysis of their strengths and limitations.

2.2.1 C&D wastes

As highlighted above, a viable way to embed circular economy principles in the construction industry is through the strategic reuse of C&DW through the deliberate redesign of systems and processes. By creatively rethinking how we manage and reuse these wastes, we are not only mitigating environmental impact, but also fostering a paradigm shift towards a more efficient and conscientious construction ecosystem.

Construction and demolition waste (CDW) is one of the largest waste streams, accounting for 30-40% of total solid waste; and it is the result of construction, renovation, and demolition activities.

Demolition waste (DW) is a highly heterogeneous mixture of inert and non-inert waste with hazardous and untreated materials and represents more than 50% of total CDW. DW management is therefore a major challenge for the construction industry. (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021)

Directive 1999/31/EC, Art. 2(e) defines "inert waste" as "solid waste that does not undergo significant physical, chemical or biological transformations; inert waste does not dissolve, burn or undergo any other physical or chemical reaction; it is not biodegradable and, in contact with other materials, does not give rise to harmful effects which could result in environmental pollution or harm to human health".

The materials that fall into the category of inert wastes are sand, gravel, expanded clay, vermiculite and perlite, cement mixtures, rubble, bituminous conglomerates, cement, bricks, tiles, ceramics, plaster, non-hazardous processing residues from demolition or construction sites.

C&D wastes are often handled carelessly, triggering technical, operational, economic, social and environmental problems; especially in developing countries. Harms include acidification of soil and groundwater, depletion of the ozone layer, global warming, respiratory effects from particulate matter, premature deaths and destruction of virgin soil. (Mahpour, 2018)

In 2017 alone, 20.4 million tons of construction and demolition waste was generated in Australia. Approximately 66% of this was recycled. By comparison, in China, as much as 1.8 billion tons of CDW is generated yearly, with a recycling rate as little as 5%. Worse still, much of this is disposed of in illegal landfills. (Rayra Brandao, 2021).

In order to optimise the management of C&D waste and to keep the residual quality of the waste products high, the circular economy is a steppingstone. (Mahpour, 2018). The CE's aim is to maintain the added value of C&D waste by recycling these materials into new production loops.

2.2.2 Barriers

C&D waste has a terrible environmental impact that is increasingly seen as a matter of public interest. The transition to a circular economy is a growing need in the construction industry. (Mahpour, 2018) surveyed industry experts and used a data aggregation method known as fuzzy TOPSIS to rank the most significant barriers to the achievement of this goal. The study found that the barriers are many and varied: behavioural, technical and legal.

(Thomas B. Christensen, 2022) similarly has identified a number of barriers related to selective demolition, quality assessment and the business model, which can be divided into the same categories as the previously mentioned research.

From a technical point of view, the difficulties of selective demolition are undoubtedly the lack of experience and the structural complexity of the buildings, which make the demolition operations difficult to execute while trying to respect the quality and integrity of the materials.

The main technical barrier is indeed the lack of effective processes, which makes circular practices more complicated and time-consuming. In fact, the use of standard processes could have led to an ecosystem of technologies capable of moving forward. Situation like this one could be solved by using different approach or by referring as primary input in a different form and matter; like for example instead of breaking down an infrastructure by pieces like stone and bricks it could be decomposed in bigger unit. This may be the case in which buildings are made by standard component like wall and juncture, as it is exposed in the **Chapter 3.4**.

With regard to selective demolition, the development of these skills and knowledge requires a number of stakeholders along the value chain interested in a change of direction in the industry.

From a behavioural point of view, selective demolition is seen as time-consuming and costly; moreover, there is still no legal framework regulating its compulsory use and/or an incentive system to promote its dissemination. (Thomas B. Christensen, 2022)

Once again, in order to fully understand the complex mechanisms of the sector, it is essential to adopt a holistic approach, taking into account a whole range of variables among the stakeholders involved.

(Mahpour, 2018) provides an overview of potential barriers to the transition to a circular economy with regard to the management of C&D waste. Using the fuzzy TOPSIS method to aggregate data from the survey of industry experts, they ranked the main barriers, focusing on technical, legal and behavioural aspects.

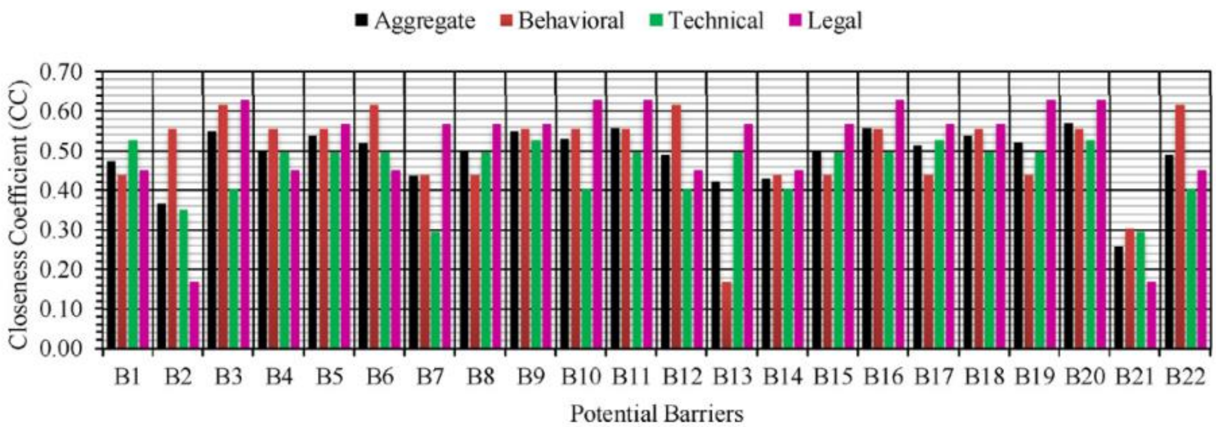


Figure 2.2.2.1 "Barriers to C&D waste management" (Mahpour, 2018)

As depicted in **Figure 2.2.2.1,** from a regulatory perspective, the main barriers are the inherent complexity of transforming waste management into a circular economy and the lack of integration for sustainable management.

From a technical point of view, the main difficulty is the inefficient management of dismantling, sorting, transport and recovery processes.

(Agarwal, 2016) and (Tomáš Mandiˇcák *, Impact of Information and Communication Technology on Sustainable Supply Chain and Cost Reducing of Waste Management in Slovak Construction, 2021) stress the prevailing gaps in existing processes, and these voids present an opportunity for leveraging IT solutions. Through the implementation of such technological tools, tracking and managing the diverse components could be significantly enhanced, facilitating comprehensive quantitative analyses. These analyses are pivotal for evaluating the viability of solutions like (Thomas B. Christensen, 2022)'s proposal of selective demolition, not only in terms of feasibility but also concerning potential economic returns. By harnessing the capabilities of IT, the construction industry can access a data-driven framework to inform decision-making, address inefficiencies, and promote strategies that align with both sustainability and financial considerations.

Finally, from a behavioural perspective, the main barriers are the actual use of recycled materials in the construction of new buildings and the lack of an empirical literature base. Regarding the business model, technical barriers are constraints from a behavioural perspective, also because of the lack of historical data on the performance of recycled materials, which makes their use also risky.

Similarly, the lack of technical and legal frameworks and lack of certifications make it difficult to carry out aggregated analyses when assessing quality. Quality assessment is essential to reassure users and increase confidence; as it become more common, it is important that they are supported by tools such as BIM.

User experience UX is another one of the main barriers as also highlighted by (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021).

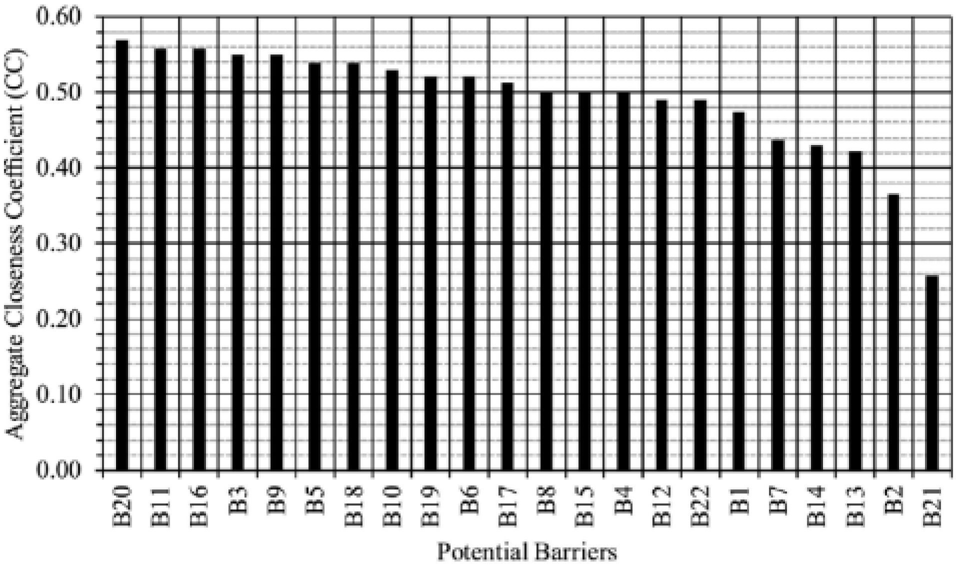


Figure 2.2.2.2 "Potential barriers" (Mahpour, 2018)

From a global perspective (**Figure 2.2.2.2**), the main barriers are the agency and ownership issues in C&D waste management, the lack of integration between the different actors and all the uncertainties related to the transition to a circular economy in this sector.

Another obstacle is that the volume of restoration work is relatively small and there is a lack of uniformity and consistency in the quality of materials. The only material for which there was consistency in supply was brick, due to its standard shape and size, making it easily replaceable.

Business model and market maturity is also needed to increase both supply and demand for reused and recycled CDW to ensure that building elements and materials can be used in the construction of new buildings. Wooden floorboards vary too much in shape and size, making it difficult to meet market demands. Therefore, one of the main challenges is the implementation of a physical and digital marketplace. (Thomas B. Christensen, 2022)

(Tomáš Mandiˇcák *, Impact of Information and Communication Technology on Sustainable Supply Chain and Cost Reducing of Waste Management in Slovak Construction, 2021) emphasises that these issues are not only of scientific interest, but also practical in terms of getting industry to understand them.

Another barrier identified in the literature is the limited availability of analytical estimates and objective data, as most papers refer to the aggregation of data from surveys of experts in the field, where subjectivity often prevails.

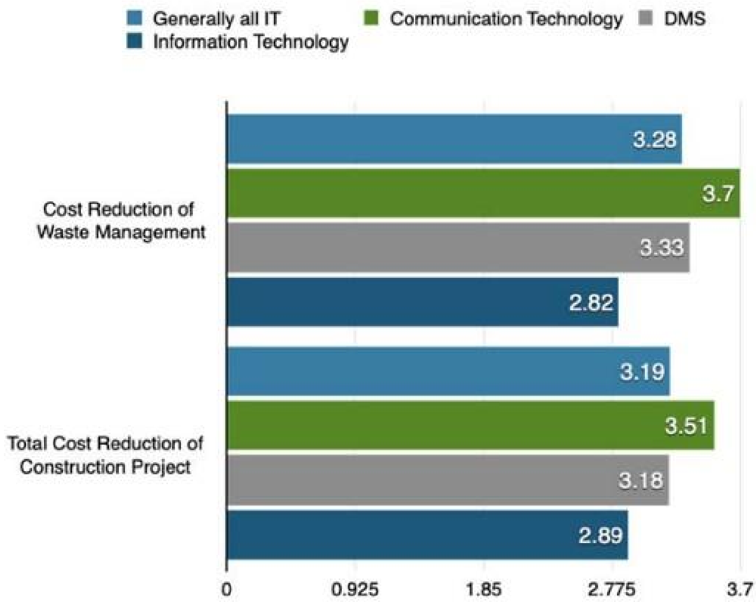
It has also to be said that the barriers identified in (Mahpour, 2018) 's study are derived from a literature review, so they inherit its shortcomings, including, as mentioned earlier, the lack of a solid technical basis derived from empirical experienced.

2.2.3 IT Impact

Efficiency in the CI sector means optimising costs and waste management while maintaining a high quality of infrastructure and construction in general. The use of IT technology as a monitoring and management tool is also crucial.

(Tomáš Mandiˇcák *, Impact of Information and Communication Technology on Sustainable Supply Chain and Cost Reducing of Waste Management in Slovak Construction, 2021) In their research, they use a survey to identify and collect data to analyse the impact of information and communication technologies on the sustainable supply chain, costs and waste management.

The impact was assessed at each stage of a construction project: pre-design, design and construction. The different phases were monitored using information from completed construction projects that were in use at the time. The respondents rated the impact on a scale of 1 to 5 (where 1 is the minimum impact of IT on sustainable supply chain and cost reduction and 5 is the maximum impact). Finally, Cronbach's alpha was applied to the survey sample.

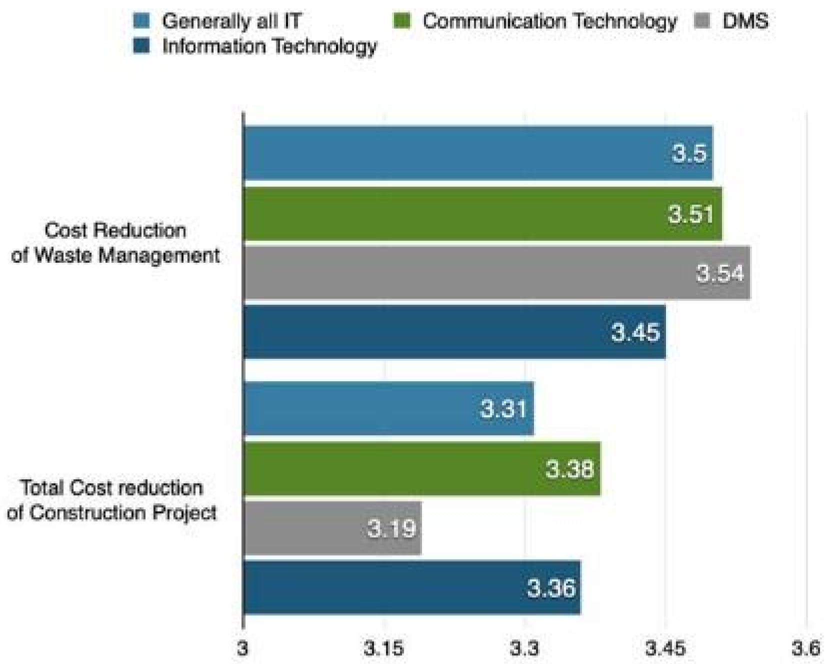


The impact level of the use of information and communication technology on cost reduction in the pre-design stage.

Figure 2.2.3.1 "Impact of IT in cost reduction in the design phase"

The **Figure 2.2.3.1** shows that during the pre-design stage, on average, the impact of IT technologies is more relevant to reducing waste management costs than to reducing the overall cost of a construction project.

The survey result thus shows that it is generally believed that investment in IT tools in this stage, can have the most relevant impact on C&D waste management; in fact, by tracking all materials upfront in the pre-design phase, it will be easier to estimate recyclable materials. Moreover, as this sector hasn't been studied much, there's still much to improve and it could be an interesting area for research and investment.



The impact level of the use of information technology on cost reducing in the construction stage.

Figure 2.2.3.2 "Impact of IT in cost reduction in the construction phase"

The **Figure 2.2.3.2** also showed that the same trend is occurring in the construction phase, making it relevant to the development of these technologies.

As we look to the future, the construction scene is gearing up for some exciting changes with the coming wave of IT solutions. These technological innovations are set to shake up the old ways and usher in a new era of increased efficiency, teamwork and progress. As these IT solutions continue to evolve, they'll completely change the way we conceive, plan and execute construction projects.

2.2.4 The importance of stakeholders

The involvement of stakeholders is vital due to their diverse perspectives, informed insights, potential conflicts, and essential role in decision-making, all of which together contribute to the outcomes of any strategy adopted by companies.

The literature on stakeholder theory suggests that external stakeholders, through their influence, generate and provide useful information for internal stakeholders to make decisions that are necessary for the performance of their duties.

Uncertainties that arise from external factors outside the supply chain and are not under the direct control of the organisations in the supply chain are defined as 'macro-level uncertainties' An organisation needs to identify macro-level uncertainties because failure to do so has a negative impact on organisational performance; for example, some commercial actions of competitors or regulatory acts can completely disrupt entire reverse logistics strategies in the construction industry. (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021).

To truly speak of a circular economy within the construction industry, it is necessary to create regenerative development with a system-wide approach.

Global challenges such as climate change can be seen as an opportunity to develop co-agency between different cultures and fields, towards a common purpose that can reconcile the fragmented relationship between human and natural systems.

Most sustainability approaches use traditional reductionist approaches to solving problems by applying best practices, focusing on social and environmental health. It is not just about reducing impacts or doing good things to nature, it is about recognising that we are part of nature and that our activities need to be designed and integrated in such a way that they contribute and add to the whole, not just extract from it.

A critical aspect is the development of strategic systemic thinking skills to maximise stakeholder engagement and commitment required to ensure regenerative design processes achieve maximum systemic leverage and support. (Dias, 2018)

Ineffective external stakeholder influence prevents successful adoption of RL. (Govindan & Bouzon, 2018) found that lack of legislation or inappropriate legislation is a major barrier to waste management worldwide.

(Carter & Ellram, 1998) claimed that customers, suppliers, competitors, and governmental agencies can have an impact on RL performance, irrespective of the industry.

Although internal stakeholders are involved in decision-making processes and external stakeholders have no formal authority, they have the power to indirectly influence the tactical and strategic decisions of companies. In fact, it should not be taken for granted that most of a company's flows are with the outside world, such as monetary flows, economic flows, information and material exchanges. (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021).

Therefore, external stakeholders are a major source of uncertainty, so it is necessary to constantly monitor the trends of these actors and of the market in general, in order to avoid having consistent operational strategies within the company, but which are destined to turn into so-called 'black swans' due to 'macro-level uncertainties'.

This concept has a strong application when it comes to reverse logistics activities, which cannot take place without the support of external stakeholders. (Carter & Ellram, 1998) claimed that customers, suppliers, competitors, and governmental government agencies can have an impact on RL performance, irrespective of the industry.

This may be due to the existence of potential safety regulations or to customers who have concerns about the safety and quality of used materials, both of which can hinder the use of such materials.

2.3 A case study on selective demolition in Denmark

(Thomas B. Christensen, 2022) Explored the creation of a closed loop production and consumption value chain based on a case study on the Bornholm Islands in Denmark. The firms under analysis used Selecive Demolition technique and conduct experiments on construction and demolition activities.

Selective demolition is one of the most important steps in CDW recycling as it uses alternative methods to map, separate and sort materials for reuse, recycling and recovery. Demolition data has been gathered and analysed, in order to quantify the costs, market values and potential CO2 reductions associated with the recycling of each material.

Before each demolition, audits were carried out to identify resources and materials that could be reused, after careful screening for potentially toxic substances. The materials selected for reuse were bricks, granite blocks, beams, wooden floorboards, tiles, and door with frame. However, a pre-demolition audit can never assess the actual amount that are available for reuse, since it is quite difficult to assess ex ante the condition of the products at the end of the demolition.

In the Bornholm experiment, the researchers were able to simulate a closed-loop environment focusing exclusively on the perimeter of the island subject of the experiment. The aim of their research was to carry out market and cost analyses of different selective dismantling activities for a specific sample of components.

These analyses are useful to understand the economic feasibility of these operations and to assess their hypothetical profitability. They included an analysis of operating and management costs, as well as market research to assess the attractiveness of the finished products to customers.

To quantify the costs, the additional time spent on mapping and data collection activities and the time spent on selective demolition activities and procedures were taken into account. So, the total cost associated with the selective demolition procedure was assessed by adding the additional time spent by the municipality and the cost spent by the demolition contractor.

On the other hand, the sales values were determined through a market analysis using existing online platforms that sell similar materials. The most reliable data were those for bricks, as in this case there is a relatively mature market for recycled bricks in Denmark.

Figure 2.3.1 shows the utilisation rate as the percentage of materials that can be returned to the market compared to the total quantity identified during the resource mapping in the pre-design phase.

Recyclable materials from the three demolition projects.

Material	Resource mapping	Amount for reuse	Utilisation rate*
Bricks	121.1 tonnes	82 tonnes	68%
Granite blocks	22 pieces	19 pieces	86%
Wooden beams	12.2 m^3	12.1 m^3	99%
Wooden floorboards	219.6 m^2	94.6 m^2	43%
Tiles	107.0 m^2	92.8 m^2	87%
Doors with frames	42	40	95%

* The utilisation rate is the percentage of materials that were reused out of the total amount of materials that were estimated to be available for reuse.

Figure 2.3.1 "Utilisation rate of recycled material"

These results suggest that some materials are easier to selectively recover and reuse, recycle or reuse than others; in fact, analysing the results we can see that the highest utilisation rate is for framed doors and wooden beams. Instead, the lower level of reuse is the one related to wooden floorboards.

This is due to the fact that there are technical difficulties in the demolition process which tend to drastically reduce the quality of the pieces extracted, and therefore a redesign of the entire upstream process becomes necessary in order to optimise the recovery of wooden floorboards.

The rate of re-use must also be linked to feasibility and economic viability, so that this business can be seen as a viable option in the long term and adopted by companies as a strategic solution.

Total cost associated with the demolition and estimated sales value.

Material	Total cost (DKK)	Total estimated average sales value (DKK)	Average profit factor
Bricks	354,510	788,777	2.2
Granite blocks	4604	12,069	2.6
Wooden beams	22,635	19,463	0.9
Wooden floorboards	16,098	82,928	5.2
Tiles	12,029	25,037	2.1
Doors with frames	28,415	29,688	1.0

Figure 2.3.2 "Average profit factor"

The potential profit factor in **Figure 2.3.2** was identified by dividing total (potential) sales value by the total cost. As shown in the figure, it is the wooden floorboards that have the highest profit factor and therefore need to be addressed, as there is still progress to be made in terms of the reuse rate, which is the lowest ever.

Granite blocks, on the other hand, are a viable option as they offer a good compromise between the percentage suitable for reuse and the profit factor.

The purpose of the assessment was to identify hotspots to assist decision makers in determining which fractions to consider when planning demolition projects; and the companies involved in the study started a training programme for employees on selective demolition, as they saw a business opportunity. (Thomas B. Christensen, 2022)

In addition to studies on the economic feasibility of reintegrating used materials, the other main objective of the research was to use selective demolition as a tool to introduce the concept of circular economy into the reverse logistics of the construction industry. This is why it is essential to assess the potential CO2 reduction associated with the reuse of materials, focusing on a life cycle perspective.

In their calculations, they compared the amount of CO2 produced by the extra processing required to selectively extract the materials with the amount that would have been produced by the various processes used to process the raw materials themselves.

In the scope of the research, the emissions associated with the logistical phases of transport, delivery and storage are not taken into account.

CO_2 assessment.

Material	Quantity	Process and reference	unit	C-intensity	Carbon footprint avoided from material reuse	
Bricks I	82 kg	EU 28 Facing brick, EN 15,804 A1-A3 Clay based (GaBi, 2019)	kg CO_2-eq/kg	0,24	t CO_2-eq	19.96
Bricks II	82 kg	Report value (Danish EPA, 2013)	kg CO_2-eq/kg	0,1036	t CO_2-eq	8.50
Granite stone	1.881 kg	EU-28: Tiles and slabs from natural stone (average) - Euroroc (A4) ts-EPD (GaBi, 2019)	kg CO_2-eq/ton	20,5	t CO_2-eq	0.04
Wooden beams	3.901 kg	EU-28: Solid construction timber (softwood) (EN15804 A1-A3) ts (GaBi, 2019)	kg CO_2-eq/m3	161	t CO_2-eq	0.63
Wooden floorboards I	20 kg	AU: Hardwood timber, kiln-dried, dressed, untreated (EN 15,804 A1-A3) FWPA (GaBi, 2019)	kg CO_2-eq/m3	489	t CO_2-eq	0.34
Wooden floorboards II	20 kg	US: Redwood Decking (California) CORRIM (GaBi, 2019)	kg CO_2-eq/m3	90,3	t CO_2-eq	0.06
Wooden floorboards III	1.864 kg	Report value, Massive Parquet – Germany (VTT 2013)	kg CO_2-eq/kg	2,94	t CO_2-eq	0.14
Tiles I	3.093 kg	CN: Stoneware tiles unglazed ts (GaBi, 2019)	kg CO_2-eq/kg	0,34	t CO_2-eq	0.04
Tiles II	3.093 kg	EU-28: Concrete roof tile (A1-A3) ts	kg CO_2-eq/kg	0,24	t CO_2-eq	0.03
TilesIII	3.093 kg	Ceramic Tile, Finland, Report value (VTT 2013)	kg CO2-eq/kg	0,61	t CO_2-eq	0.08
Internal doors with frames	40 pieces	Internal Door – Sweden (VTT 2013)	kg CO_2-eq/unit (50 kg / door)	18,45	t CO_2-eq	0.74
Total (max)					t CO_2-eq	21.3
Total (min)					t CO_2-eq	10.0
Total (average)					**t CO_2-eq**	**16,2**

Figure 2.3.3 "CO2 Assesment"

The report in **Figure 2.3.3** shows the environmental impact of the different materials in the case study, giving both the kilograms of CO2 equivalent and the references to the characteristics of these materials.

Kg CO2 equivalent" is a unit of measurement used to compare the global warming potential of different greenhouse gases. It allows the standardisation of different greenhouse gases by expressing their warming effect in terms of carbon dioxide (CO2) emissions. This concept t is crucial for the assessment and management of greenhouse gas emissions, climate change mitigation strategies and the setting of emission reduction targets.

It helps policymakers, scientists and organisations assess and compare the climate impacts of different activities and sources, facilitating informed decision-making and the development of effective climate policies.

The report in **Figure 2.3.3** exhibits that bricks have the greatest environmental potential, followed by granite blocks. In this case, Reductions in tonnes of CO2 equivalent may be overestimated due to the lack of a specific baseline. Overall, selective demolition has several economic and environmental advantages over traditional demolition.

(S. Pantini, 2020) carried out research on a residential complex in Milan with the aims to critically examine the sustainability of selective demolition practices in comparison to traditional demolition, by addressing the environmental issues through the methodology of Life Cycle Assessment.

Their results showed that environmental sustainability depends both on the characteristics of the buildings to be demolished and on the availability of a local market willing to buy used building materials. Indeed, as has been extensively reiterated in **Chapter 2.2.4**, the impact of external actors must always be taken into account.

In fact, this can be seen as the weakness of the (Thomas B. Christensen, 2022) research i.e., that it carried out analyses of "internal feasibility", which is useful to learn general concepts in this field but requires feedback from the availability and willingness of end users to buy recycled materials, and this aspect can only be analysed locally.

In fact, as I noticed while collecting material for my literature thesis, almost all the articles refer to a specific geographical context; this is due both to the fact that construction industry is, by its very nature, inextricably linked to the territory and also to the fact that there are so many variables to be analysed. Ignoring any of them can lead to misleading results, as macro level uncertainties can totally alter the results of any research as suggested by (Maria Ghufran 1, 2022).

2.4 Proposed Strategies for CE Implementation

(Mahpour, 2018) Emphasised the need for more in-depth and empirically based research studies on the concept of circular economy in this sector. These future studies should aim at implement guidelines for workers in the sector and disseminate to all C&D project stakeholders the quantitative, economic, and environmental efficiency consequences of non-implementation or incorrect implementation of those principles and guidelines.

There is also a need at national level to set targets and identify clear objectives towards a circular economy; this could be achieved through incentive schemes for those using recycled materials.

To facilitate the reliable predictability required of any source of secondary raw material, C&D waste should be generated in relatively constant quantities and should be easily packaged for transport to improve the economic profitability of construction wastages. (Rayra Brandao, 2021)

In terms of legislative gaps, the main uncertainties are due both to the lack of regulatory instruments and incentive system. In the legislative environment about Selective Demolition there is a lack of a specific permit for this activity; the main purpose of legislative instruments should be to protect the environment and the well-being of workers.

Another gap in the legislation is the fact that local authorities require demolition to be authorised in the building permit, but private bodies can also certify this authorisation, so there are no clear guidelines and specific criteria to be followed in the assessments.

Even if the local authorities grant the demolition permit, they do not pay attention to whether the demolition companies follow QA practices to achieve a maximum recovery rate.

These issues are due to the fact that even if there is a legislative requirement, the local government agencies do not monitor demolishers' work. (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021).

Addressing these shortcomings through precise and robust regulatory action is not only a legal imperative, but a vital step towards reconciling progress, sustainability and worker protection in the field of selective demolition.

Uncertainties at the incentive level depend on the upstream and downstream actors along the reverse logistics supply chain of the construction industry; it is indeed needed the alignment of the goal between these actors.

The RLSC (Reverse Logistics Supply Chain) of construction and demolition waste (CDW) involves internal actors who are linked to actors in the forward supply chain at two key points. Firstly, they are linked to the client, who acts as an upstream actor by employing demolition contractors to carry out the necessary work. Secondly, these internal actors are linked to potential customers after the processing of CDW into new products. These actors exert their influence on the work of the demolition company through the conclusion of contracts.

One of the major problems is time constraints at the contractual level, as clients tend to require these activities to be carried out in the shortest possible time, leaving no room on site for time-consuming activities such as selective demolition.

Once again, the strategy proposed by (Madduma Kaluge Chamitha Sanjani Wijewickrama 1, 2021) is precisely that of reforming legislation in this area, which unfortunately requires a deep theoretical foundation to be laid.

The General Insurance Statistical Agency (“GISA”) plays a crucial role in promoting the circular economy by supporting various industries. One of its main functions is to provide subsidies to encourage industries to adopt sustainable practices and technologies for processing waste and creating new products from it.

GISA offers funding options in the form of grants and loans to specific recipient groups, including local government agencies, NGOs, research institutes, and businesses involved in the production, manufacturing, sale, or promotion of recycled products.

However, it has been observed that the grants with significant values primarily target waste streams from municipal, commercial, and industrial sources such as plastics, paper, cardboard, glass, scrap metal, textiles, and e-waste. Notably, certain grants, like the "Recycling Infrastructure Grants," which support investments in equipment, technology, and processes for recovering and handling recyclable materials, are not available for construction and demolition waste (CDW) management projects.

3.0 Information Technology

3.1 Impact of IT

According to a report by McKinsey Global Institute in 2017, the global construction sector faces a staggering annual productivity gap amounting to $1.6 trillion. Seizing the opportunity presented by this gap requires the industry to introduce efficiencies, with digitalization emerging as the foremost catalyst for transformative change.

However, an observable tendency persists among construction firms to allocate insufficient resources towards information technology (IT) and technological advancement, often sidelining research and development (R&D) endeavours. (Jennifer Li*, 2019)

These have been attributed to a layered approach that includes streamlining processes, vigorous curbing of corrupt practices through advocacy of transparency, substantial investment in R&D initiatives, formulation of standardised building codes, and an unwavering focus on optimising project outcomes.

Construction is an industry built on traditional methods and techniques that have been used for centuries. This has led to a resistance to change and a reluctance to adopt new methods and technologies.

Although automation has been actively and successfully used in different industries since the 1970s, its application to the construction industry is still rare or not fully exploited. (Borja Garcia de Soto, 2017). Studies show that the construction sector's productivity has been stagnating in recent decades worldwide and that it has not been able to keep pace with the overall economic productivity (Bock, 2015)

The industry is also perceived as slow to innovate, particularly in its adoption of digital technology (Agarwal et al., 2016)

The causes are numerous and include factors such as the resistance to introduce changes in a highly traditional sector, low industrialization of construction processes, poor collaboration and data interoperability, and high levels of turnover, which make difficult to implement new methods (Teicholz, 2013)

Another reason for the slow pace of innovation is the fragmented nature of the industry, which is characterised by many small companies operating independently. This may make it difficult to adopt new technologies and processes at scale.

Compared to other industries, the construction sector has traditionally had lower levels of investment in research and development, which has limited the resources available for the exploration of new technologies and innovation.

These are some of the reasons why construction industry is still amongst the lowest sectors in innovation. (Kenley, 2016).

For this reason, one of the most frequently cited solutions in the literature for closing efficiency gaps and moving towards a circular economy is precisely the use of technological solutions to map and manage both information and material flows.

Policymakers see digitalisation as a key strategic response to common problems in the architecture, engineering and construction (AEC) industry, such as low productivity, poor value for money, poor health and safety quality and frequent disputes. (Algan TEZEL, 2020)

IT technology can be very useful in promoting sustainable supply chains, it can enable companies to collect and analyse data on their supply chain operations, identify areas where they can reduce waste and emissions, and track the environmental impact of their products. Moreover, effective decision-making requires leveraging information that rely on vast amounts of data.

The $1.6 trillion productivity gap can be effectively addressed by embracing digitalization as a prime driver for transformative change. Despite this potential, construction companies often exhibit a tendency to underinvest in IT and technology, and they tend to overlook research and development endeavours. (Jennifer Li*, 2019)

As expounded by (Maria Ghufran 1, 2022)'s system dynamics analysis, (Jennifer Li*, 2019) concurs that the facilitation of industry change can indeed be achieved through improvements and alterations in regulations.

This proposition finds empirical support in the experiences of Australia, Germany, and Singapore, where tangible positive impacts have materialized. Notably, these countries have effectuated industry transformations by streamlining processes, engendering transparency to combat corruption, investing in research and development initiatives, establishing more standardized building codes, and accentuating the primacy of project outcomes. Such regulatory measures have been instrumental in fostering advancements and progress within their respective construction sectors.

In the article (Tomáš Mandiˇcák *, 2021) the authors provide an overview of information and communication technologies and their impact on supply chain and cost management of waste in construction.

They started their research with the assumption that minimizing the consumption of materials means minimizing the costs, so by optimally setting the parameters of the supply chain and logistic using materials and funds efficiently will led to waste management optimization.

The other finding of this article is that the effect of new technologies in the CI, varies according to the size of the firms. Larger companies reported a bigger impact on cost reduction rather than smaller one, thanks to their ability to reach economies of scale.

Another finding is that ICTs' impact on the sustainability of supply chains varies across different stages: planning software had the most positive impact in the initial stage, while control systems like GPS and RFID were more suitable for the construction phase. The use of enterprise resource planning (ERP) systems had a constant positive impact on sustainable supply chain and cost management throughout the project's life cycle.

Given that each project has specific peculiarities and that there is no continuity of service in operations it is difficult to justify investment in new technologies that may not provide an immediate return, as construction projects are often completed within a relatively short timeframe.

Building information modelling (BIM) and blockchain represent key technological advances that have the potential to revolutionise the construction industry. BIM's digital representation of the design, construction and operational phases of a building promotes better collaboration and communication between different stakeholders.

Meanwhile, blockchain's decentralised and immutable nature ensures transparency and traceability throughout the supply chain, effectively combating issues such as delays and disputes arising from information discrepancies. By streamlining data sharing and automating processes, these technologies address long-standing challenges in the construction sector, leading to smoother operations, reduced delays and improved project outcomes.

Therefore, the next two subchapters will examine the literature in these areas more in detail.

3.2 BIM

3.2.1 Overview and functionalities

Building Information Modelling, commonly known as BIM, is a powerful digital technology that has transformed the architecture, engineering, and construction industry in recent years. It is one of the technological advances that has attracted particular attention in the world of architecture and the construction industry.

One of the main roles of BIM is related to the function of cost estimating and planning, as it is able to prepare the Bill of Material (BoM) and also the Bills of Quantity (BoQ); another important function is the ability to graphically visualise the progress of the work in relation to the planned progress.

Cost estimation is essential in order to make budgeting choices early in the design phase. The early availability of this estimation information also means that there is less rework later on, as alternative choices can be sought in the modelling and not during the procurement and construction phase, where the impacts of a change are greater and require more effort.

An early cost estimate then becomes the fundamental guideline to determine the projects' feasibility and also acts as the main parameter with which the design has to conform throughout its development. (Odusami, 20008).

The early estimation of costs is also relevant in tenders, where having a better perception of risks enables targeted and strategic decision-making. This can lead to advantages over competitors in the calculation of future cash flows that allow an offer that is economically and financially feasible.

There are many BIM (Building Information Modeling) software programs available on the market, each with their own unique features and capabilities, some of the most popular BIM software programs include: Autodesk Revit,Trimble SketchUp,Bentley MicroStation and ArchiCAD.

Below are screenshots taken directly from the software SCM (Solibri …), with reference to a specific case, which we will use to better illustrate how it works and the potential of BIM software currently on the market.

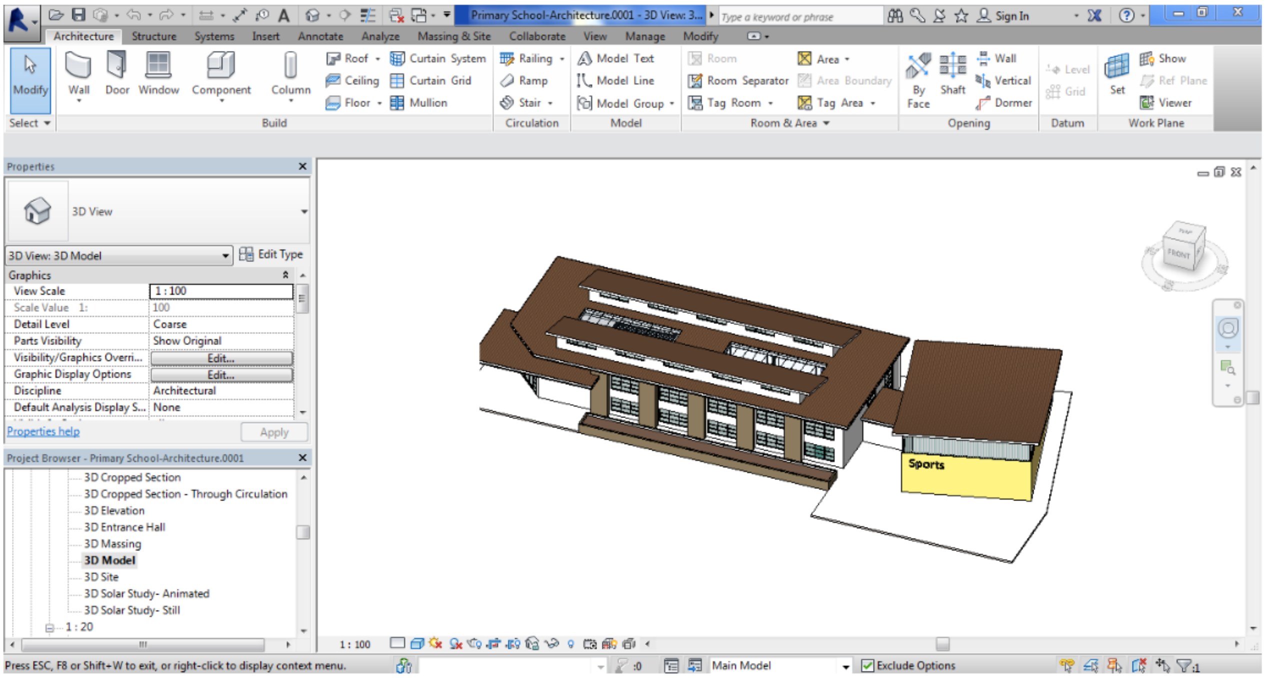


Figure 3.2.1 "3D Model" Solibri

Figure 3.2.1 shows the 3D elevation of an entire building, from which the various components, such as the different sections and areas, can be selected.

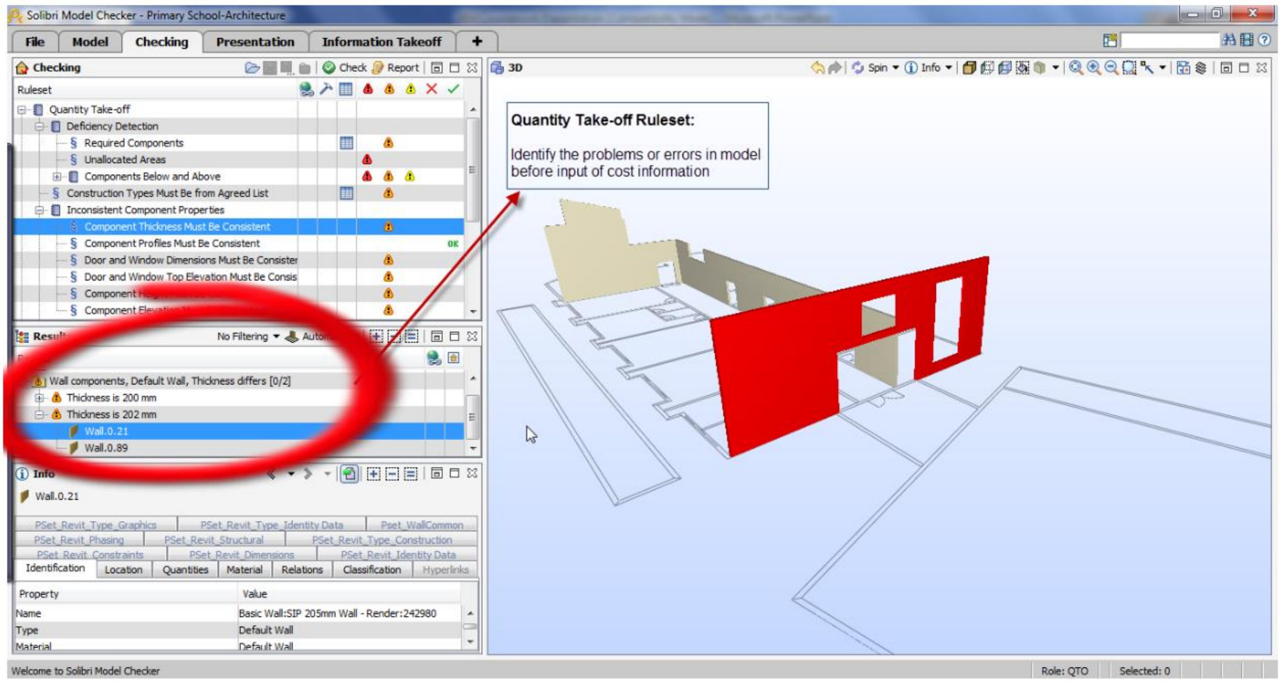


Figure 3.2.2 "Main architectural elements" Solibri

After selecting the components, engineers and architects using the software can select macro characteristics such as wall thickness, column dimensions and the width of any doors. (**Figure 3.2.2**)

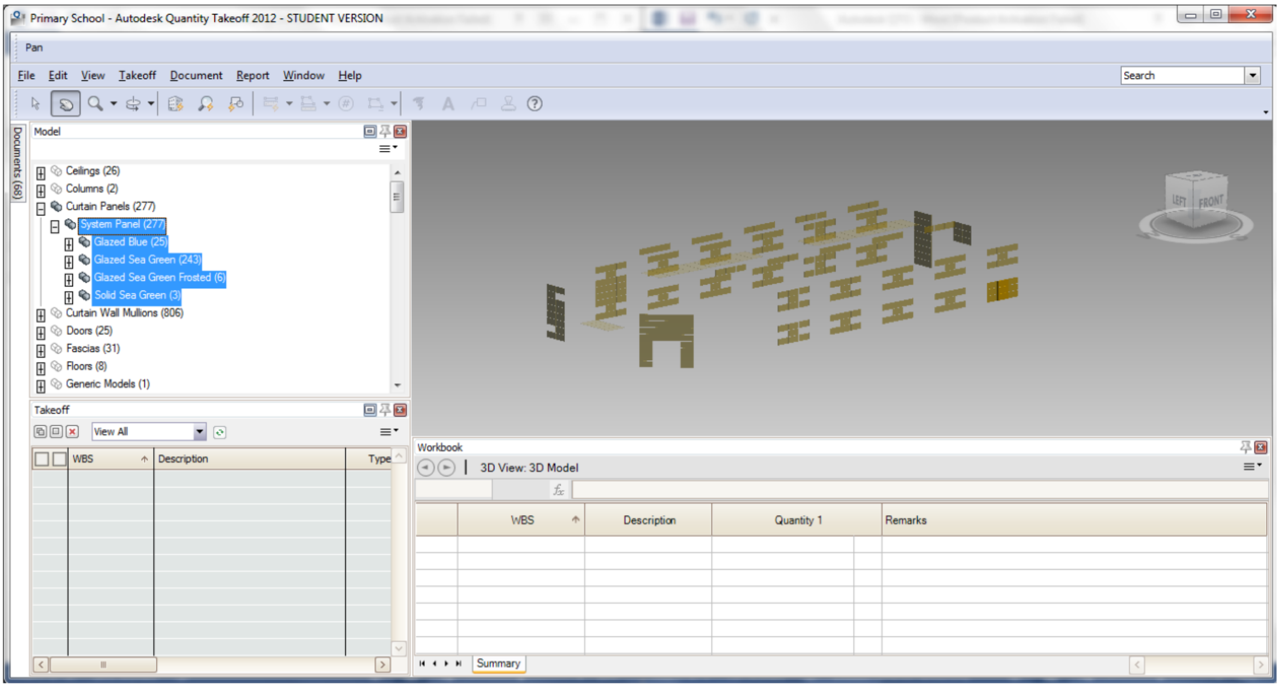


Figure 3.2.3 "Basic components" Solibri

As the basic components such as panels, bricks, doors and frames of different types are also defined in BIM software, it is possible to go into detail to visualise and quantify the materials required to complete a specific project. (**Figure 3.2.3**)

It is also possible to have real-time updates that take into account any structural and aesthetic changes. This is a huge advantage from a cost management point of view, as the impact of operational decisions on the budget can be assessed as they are made.

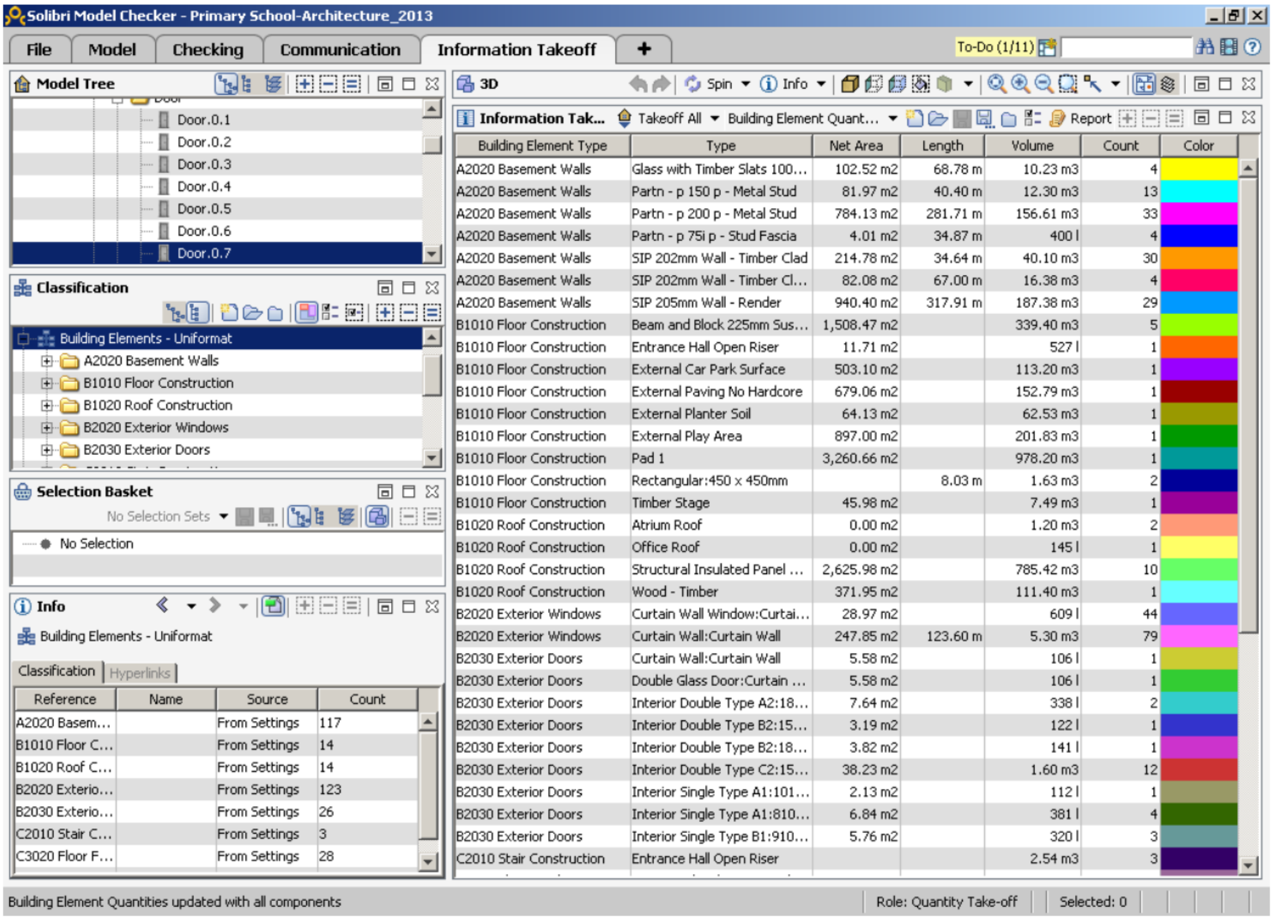


Figure 3.2.4 "Information takeoff" Solibri

The information in the BIM software is often linked to information in the warehouse, so that decisions can also be made about the types of materials to be used. This is also advantageous from a logistical point of view, as it is possible to see whether materials are in stock or not, depending on the stage and progress of the work, and to plan orders that are close to JIT management.

BIM can be summarised as the process and technology for producing, managing, and sharing physical and functional data of a facility in a collaborative environment using digital representative models throughout project lifecycle processes. (Song Wu, 2014).

The ability of BIM to have automatic measurements for a fast estimation process remains one of the most important features, because it brings operational efficiency through the ability to update the digital building schematic simultaneously with design and budget choices.

In the article 'Examining critical perspectives on Building Information Modelling (BIM) adoption in New Zealand' (Dat Tien Doan, 2020), many other benefits of using BIM were identified through a survey of industry experts with over a decade of experience. Although building industry literature is always localised to a specific country, many aspects are general in nature and can be extended beyond national borders.

One of the main benefits that has emerged is the time saved due to a number of efficiencies and improvements that can be attributed to the use of this technology, such as: improved collaboration and coordination, reduced rework, improved visualisation, risk reduction, clash detection and variation reduction. (Edirisinghe, 2015)

As one project manager interviewed put it: “Having all their information is stored centrally as well as all of the other project information in one place, it works extremely fast because you are not doing anything that will be aborted”. (Dat Tien Doan, 2020)

In addition, the ability to visualise the 3D assembly increases not only coordination but also the transparency and clarity of design information. Visualisation helps to improve safety by identifying dangerous areas and allowing safety measures to be taken immediately. The fact that all parties are working with the same information reduces information asymmetry, and the smoother and more efficient chain is also perceived by the end customer, leading to increased customer satisfaction.

The extent to which individual contractors are involved in the use of BIM is a choice dictated by their individual strategies; the ability to calculate a score for analysis at an individual contractor level is useful for later aggregation and analysis at a national group level.

McGraw Hill Construction in 2014 has developed a "BIM Engagement Index" to quantify the level of commitment with a numerical score. This score takes into account several factors such as: the number of years the contractor has been using BIM, the level of experience and technical expertise, and the percentage of projects on which BIM has been used. Each of these criteria has a specific weight in the formula according to its importance. (Harvey M.Bernstein, 2014)

Their research data showed that the level of commitment is correlated with the size of the companies in the sample analysed, and it was found that more than 50 per cent of companies using BIM in an influential way were large companies. (**Figure 3.2.5)**

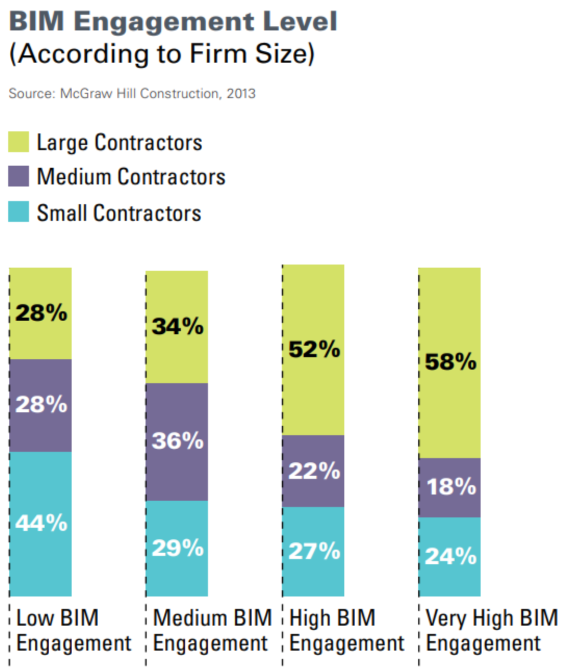


Figure 3.2.5 "BIM Engagement Level"

To sum up, with the implementation of BIM far-reaching changes can be achieved throughout the construction industry, at every stage of the building lifecycle.

There are a vast number of BIM-based estimation tools on the market; however, choosing the best software is not easy; there is no one-size-fits-all solution, enterprises need to choose the software that can maximise performance, taking into account the file format used, the information provided and the boundary conditions.

3.2.2 Barriers in BIM adoption

Again, with reference to the interview of industry experts in (Dat Tien Doan, 2020), a number of barriers to BIM implementation emerged. The main barrier is the lack of knowledge of what BIM is, both among customers and stakeholders.

This is a key barrier, which needs to be resolved to enable the development of this technology. Since there are also no performance benchmarks between the realisation of a project with and without the use of BIM, there is also a lack of interest.

In fact, as one industry interviewee reported: "if somebody experiences no benefits, they are going to be reluctant to do it". Similar considerations lead the reader to think that often in everyday working reality pragmatic and short-term considerations can take over strategic decisions.

Another barrier is the high investment required, including software licences, training, and recruitment of specialists. It is precisely this last aspect that is considered critical due to the lack of expertise; since there is still a lack of BIM experts in the market, ranging from architects, civil engineers, BIM managers and BIM coordinators.

Another factor negatively affecting the uptake of BIM is the lack of demand from clients, due to bad publicity from architects and engineers selling BIM as an expensive tool that demotivates clients. This phenomenon is due to the first major barrier mentioned above: lack of knowledge, which creates a vicious circle in which clients are demotivated by architects and engineers, and promoters are held back by low demand. That's one reason why there's growing cultural resistance to BIM adoption.

According to (Dat Tien Doan, 2020), one of the main challenges is also the lack of standards and guidelines; as there is no defined limit to the potential and benefits of the technology, users of such software are "pioneers", so the main approach is "trial and error".

In addition, as BIM evolves alongside CAD, the various companies that sell CAD tools tend to sell their own specific BIM solutions. This results in a lack of specific data formats and common interfaces, making it increasingly difficult for the various players to work together. In fact, it is plausible that designers, architects and engineers use different CAD software as they have different underlying needs, which may hinder the integration of the different modules with BIM.

3.2.3 BIM Integration

The manufacturing and production industries have successfully integrated computer applications such as the Internet of Things (IoT) into their processes, and their economic development was thus greatly enhanced. On the other hand, the construction industry has not participated much in these digital transitions and is still a very young sector in this respect, where the possibilities for research and innovation are still many and unexplored. (Syed Uzairuddin ⥣, 2022)

There is also a popular belief that the construction sector is anchored in traditional practices that have been known for more than a century; but this is not entirely true, as the so-called 'Industry 4.0' will bring radical change to this sector as well. (Ballard, 1997)

One of the areas of research in the academic literature is the greater involvement of BIM to achieve the integration of ever broader processes and activities, taking into account not only on-site activities but also logistical support both on and off site.

Among these integrative modules for BIM, there are mapping systems such as the Geographical Information System GIS and the Web Map Service WMS, each of which is being considered by (Syed Uzairuddin ⥣, 2022) and (Po-Han Chen, 2019).

As noted by (Syed Uzairuddin ⥣, 2022): "The convergence of BIM and GIS creates a complete digital representation of the physical environment. BIM may be used to produce, manage, and exchange operational data of building structures, whereas GIS could be used to handle the logistic aspect of the construction project and store, organize, and analyse data representing the horizontally spread urban environment.”

One of the main causes of poor performance in the construction industry is the inefficient use of resources. (Syed Uzairuddin ⇑, 2022)

The integration of logistics software with construction processes allows the flow of raw materials to the site to be tracked in real time. Excellent management of the resource procurement process is precisely one where materials are scheduled and delivered at the right time and in the right quantities. Poor procurement management can lead to a range of inefficiencies, including delayed deliveries and increased waste (E. Elbeltagi, 2011).

Currently, the most commonly used visualisation and monitoring tools to identify the current state of required building materials are simple histograms. BIM, on the other hand, allows for much more accurate tools.

These can provide a more transparent supply network with better tracking capabilities. In fact, by breaking down the design drawings into the bill of materials, one can get a very accurate estimate of the materials and finished products needed in a specific and defined time frame in which construction activities have been planned and scheduled.

The integration of software such as GIS, which also maps the logistics environment, allows for more accurate and precise delivery schedule estimates, since once the location of each construction resource is known, GIS can show the current location of the resource and predict the time it will take to reach the chosen project site. In this way, it would be possible to reduce both the gaps responsible for inefficiencies, those related to the quantity variable and those related to the time variable.

There are two primary challenges involved in achieving precise transportation route calculations. Firstly, it entails determining the optimal shipping route from the material location to the job site. Secondly, it requires accurately calculating the distance along the identified route.

An Application Programming Interface (API) can help integrate the functionality of BIM authoring tools and Web Map Service (WMS), such as Google Maps, which provides requested map images from a map server with GIS databases through the web interface.

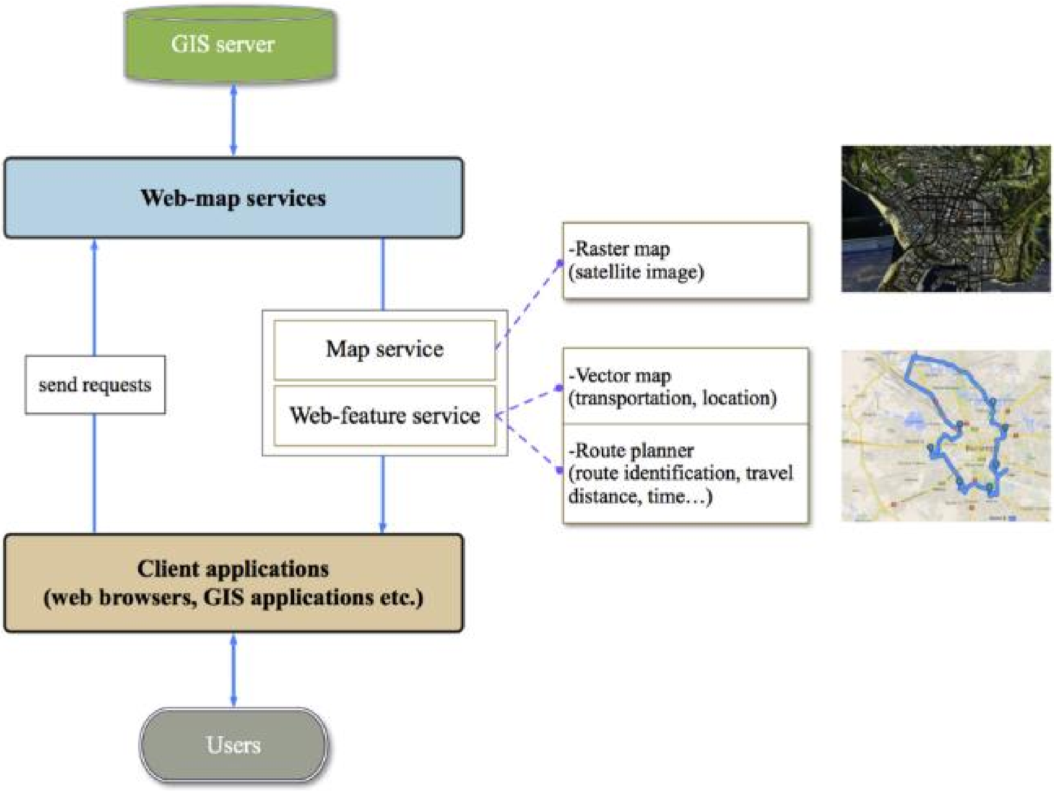


Figure 3.2.3.1 "API communication with GIS server"

Figure 3.2.3.1 shows graphically how the BIM GIS interface works, in this case the 'user' represents the BIM using a client application or API integration that sends a request to the web mapping services that, after consulting the GIS server, provide as output satellite imagery and a route planner, with travel distances and times calculated using routing algorithms.

APIs can be used to develop another BIM plugin that can also be synchronised with an already integrated BIM-GIS model to achieve full integration where the end users, in this particular case the drivers of the trucks carrying the materials, can already receive final instructions on the route to take and any other relevant information.

WMS is widely used as the map provider. However, in (Po-Han Chen, 2019) study WMS not only provides map images, but also functions as a route planner, which seamlessly integrates with BIM to identify and calculate transportation routes.

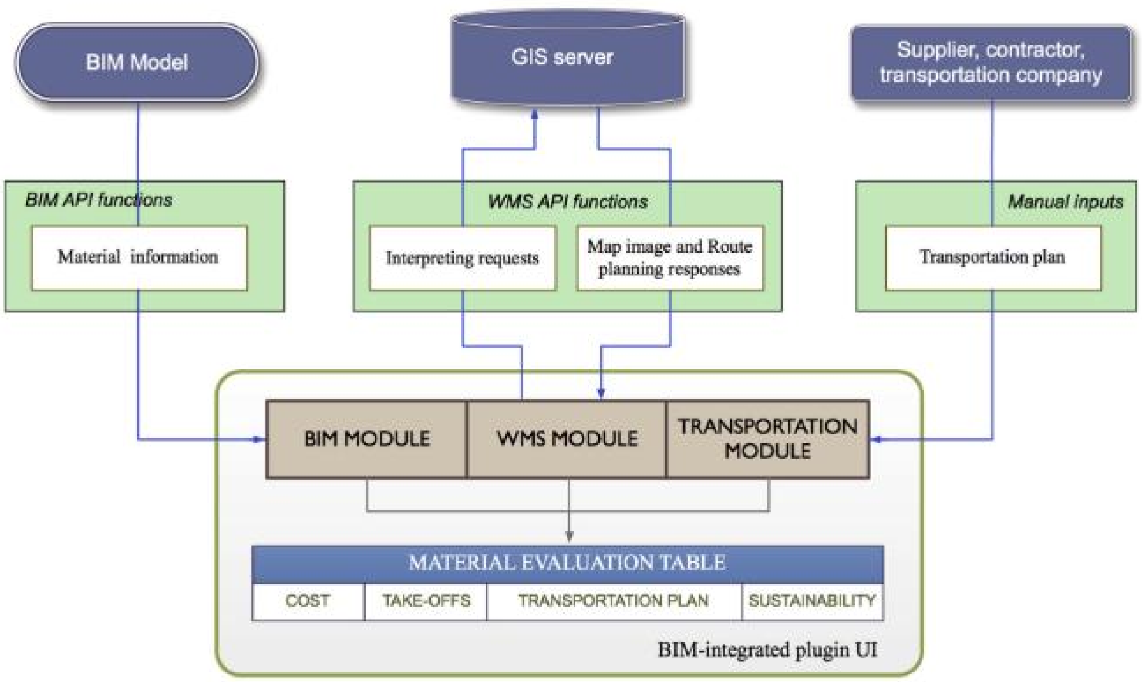


Figure 3.2.3.2 "Actors connected with BIM integratio"

From a more general point of view, **Figure 3.2.3.2** shows how the different actors are connected: BIM model, GIS server and the suppliers, contractors and transport companies. Finally, it shows how an integrated BIM interface is able to provide a material evaluation table consisting of costs, transport pains, sustainability analysis and take-offs.

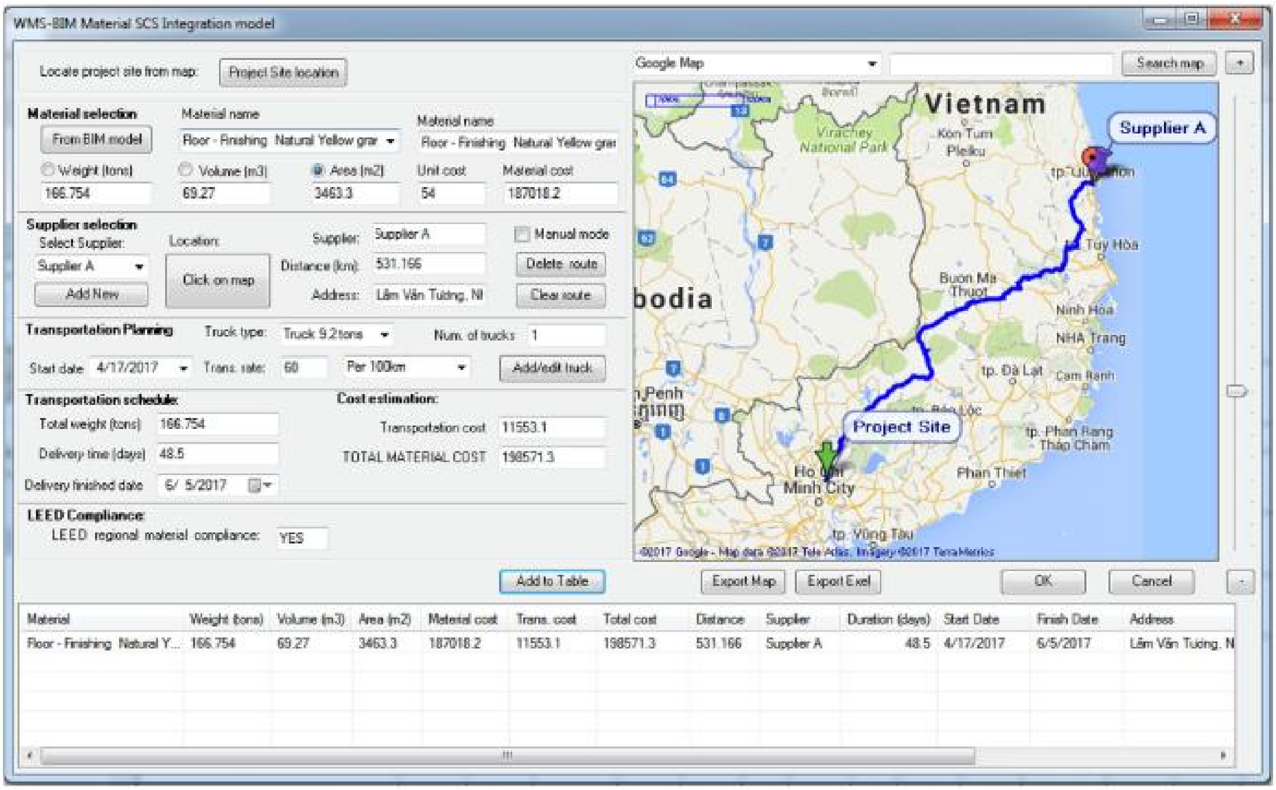


Figure 3.2.3.3 "Output of WMS-BIM Integration"

Figure 3.2.3.2 shows the output of the integrated software. It can be seen that it is possible to select the materials to be transported directly from the BIM model, specify their quantities and unit costs and, more importantly, select the supplier in real time based on the distance and schedule provided.

The impact of using this integration at a sustainable level is really important, as downstream modules of the transport planning input can be included in the information flow, taking into account environmental checks and compliance with sustainability standards to compare alternatives and make decisions; as shown in **Figure 3.2.3.4**.

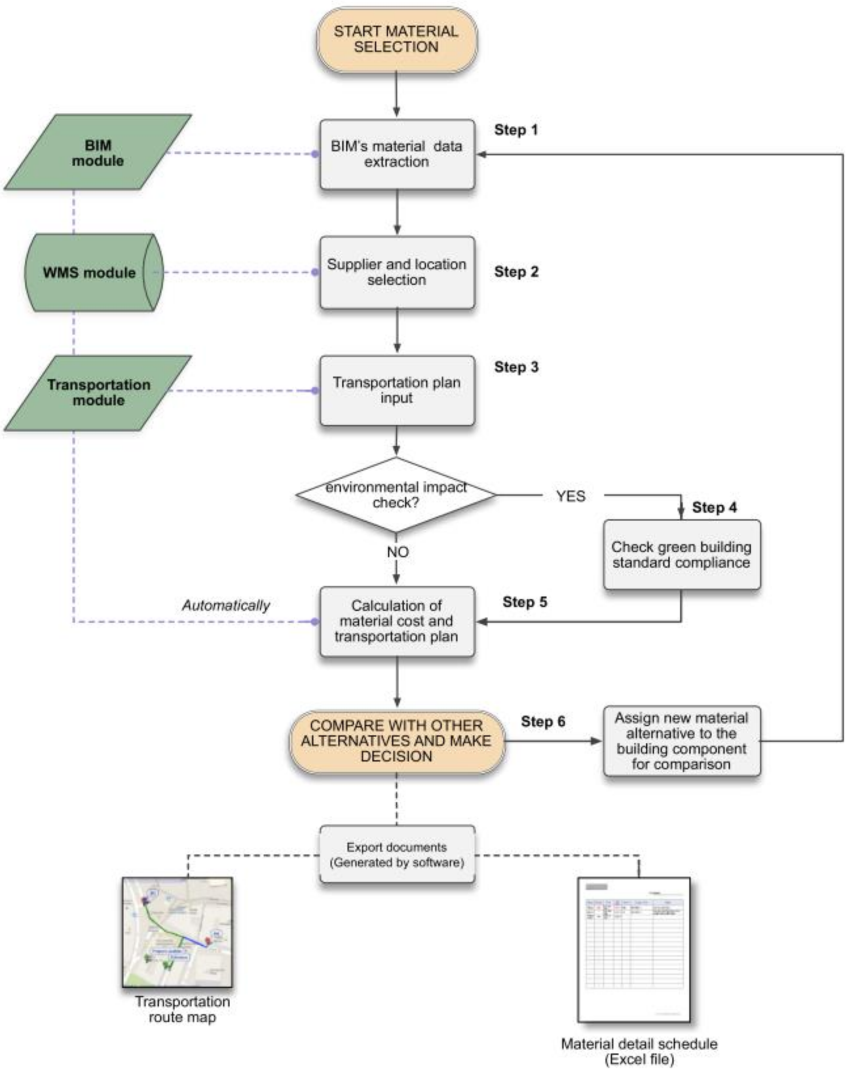


Figure 3.2.3.4 "Output of WMS-BIM Integration"

The purpose of these plug-ins and integrations is consistent with the research purpose of this literature review. That is, to highlight efficiency gaps in the construction industry and to identify technological, logistical, managerial and legislative solutions to close these gaps.

This can provide a direction in which this industry could move in terms of efficiency and sustainability. In fact, the use of these plug-ins can create synergies by making intensive use of technology and data collection, and then using operations research tools such as n-variable linear programming to optimise objective functions that take into account a variety of factors.

Several vehicle routing algorithms have been created, (M.R. Sousa Matos, 2018) introduced a conceptual model called the Green Vehicle Routing and Scheduling Problem (GVRSP). The objective of this model is to optimize the planning of deliveries conducted by a fleet of vehicles in logistics systems, with the aim of minimizing carbon dioxide emissions (CO2).

On the other hand, the GIS maps the entire supply chain, including data such as the location of supply sites, the location of warehouses and intermediate hubs, means of transportation, and value-added and non-value-added processes.

At the start of the process, spatial coordinates are determined and transformed from local coordinate systems to the real-world coordinate system, making it easier for the end user to view the data. All this data is then processed by optimisation algorithms to select the best strategy given the constraints, facilitating the creation of innovative ways of using the full potential of information technology.

The workflow of the management scheme can be summarised as follows:

In the pre-design phase, the materials required for components such as columns, walls and windows are identified, and the procurement process is initiated. Suppliers are sought for large-scale material procurement, taking into account the impact of distance on transport costs and schedule.

Research shows that approximately 60% to 65% of the total cost of a construction project can be attributed to material costs. Inadequate planning and execution of material production and delivery can lead to problems with cost control, schedule adherence and quality standards on the project. (H.P. Tserng, 2006)

The most suitable suppliers are selected based on logistics factors such as cost and time. Logistics involves controlling the movement of materials from suppliers to the construction site to meet design specifications. It includes activities such as documentation, transportation, inventory management, warehousing and material handling.

The monitoring and control phase accurately provides and documents the status and other information about materials at different stages of the project. (Syed Uzairuddin ⥣, 2022).

According to (F.F.A. Ahmadian, 2016), the transportation cost holds significant importance as the primary factor to consider when planning the transportation of construction materials. The "location" factor should be regarded as a crucial input in the material selection process, since it has a lot to do with sustainability in terms of CO2 emissions generating from shipping. Thus, regional materials should be preferred to minimize the environmental impact on infrastructure development. (Po-Han Chen, 2019).

As there are different product delivery schemes, such as Engineered-to-Order (ETO), Made-to-Order (MTO), Assemble-to-Order (ATO) and Make-to-Stock (MTS), each of which has specific characteristics at the supply chain level, BIM-GIS software also takes these characteristics into account when selecting the best strategies to implement.

Other features include a topological study of the network used to minimise warehousing and transport costs, optimising transport capacity by choosing the most efficient route, product mix and frequency of trips.

GIS relies on real-time and specific location data of resources to map their status and issue alerts, allowing managers to respond promptly to any deviations.

In the monitoring phase, various identification and tracking technologies such as barcodes, RFID and GPS have been integrated with GIS to date. These technologies facilitate the tracking of geographic locations and the immediate identification of new materials. However, the lack of a fully automated resource tracking and location system in the current model has been a challenge. (Syed Uzairuddin ⥣, 2022).

Again, as is often the case in the literature, one of the biggest barriers and difficulties to overcome is the integration of the two platforms into a single integrated environment where compatibility is not only at a conceptual level but also in terms of functionality.

Currently, one of the technical difficulties is the use of different file formats between the different BIM software, which does not allow a perfect integration through APIs that need to be further developed. Furthermore, considering the complexity of supply chains, their variety, and the number of variables affecting logistic costs, more sophisticated technology is required.

In the future, in addition to functional and technical compatibility, it is possible to add user experience integration to package these software’s into a finished product with high market value for the construction industry.

3.2.4 Policies and regulations

According to (Edirisinghe, 2015), there is a link between the adoption of BIM and BIM standards, regulations and policy initiatives.

“Even though the driving forces for digital engineering and building information modelling for construction are revealing globally, national level standardization and policy initiatives vary significantly in different countries. This can result a variation in BIM adoption because national policy initiatives as well as standardization of the regulatory environment have a significant influence.” (Ruwini Edirisinghe, 2015)

This last statement is in line with (Maria Ghufran 1, 2022) theories presented in **Chapter 1** on the analysis of system dynamics.

Indeed, from a global perspective, the impact of policies on incentive systems and the use of smart and innovative technologies has been summarised through the feedback loop of economic performance and the feedback loop of social performance.

In short, increased support from government agencies is positively correlated with the adoption of supportive policies that stimulate incentive systems.

Incentive schemes can consist of political, financial and fiscal measures that encourage firms to adopt new technologies.

Since, as mentioned in the previous chapter, the lack of software standardisation is one of the barriers to the development of new technologies, one of the first major steps towards this direction was the creation of buildingSMART. (Ruwini Edirisinghe, 2015)

The buildingSMART Alliance (bSA) is a global organisation of industry professionals, government agencies, and academic institutions dedicated to promoting the use of open standards and data exchange in the building and infrastructure industry. Founded in 1996 in the United States as the International Alliance for Interoperability (IAI), it changed its name to the buildingSMART alliance in 2005 to reflect its global focus. Among the international standards defined by buildingSMART are ISO 13567 for standardisation of CAD layers and ISO 12006 for standardisation for structural models. (Ruwini Edirisinghe, 2015).

The literature considers the integration of all software and programme layers used during the lifecycle of a construction project to be essential. This is crucial in order to reduce information asymmetries and to ensure that the flow of information is as continuous and up to date as possible.

With the exception of global associations such as SmartBuilding, the policies and regulations that support the use of intelligent technologies, and BIM in particular, are mainly national and reflect the will of different countries.

As the literature review in this area has repeatedly shown, the construction industry is so specific and involves so many factors that each context must be analysed on its own merits. Using the BIM Engagement Index (Harvey M.Bernstein, 2014), Mcgraw was able to calculate the score for several regions. The latest data available is from 2013 and shows that the US has the highest percentage of companies with high or very high BIM engagement, at around 44%.

“In the USA, the National BIM policy program was introduced in 2003. Four years later BIM was mandated in the USA. Even though, there was 28% industry wide BIM adoption in North America when the legislation mandated BIM for architectural drawings, two-year later the industry adoption reached almost half. Five years from the legislation, industry adoption reached 71%. “ (Ruwini Edirisinghe, 2015).

(Gu, 2014) In their BIM Ecosystem, they mention that government regulations are critical to encouraging the use and adoption of BIM on strategic and significant projects. However, these very strong hypotheses on the correlation of these variables require robust data collection, so that future research could examine the relationship between policies and legislation active in the construction industries of different national contexts in relation to the actual use of innovative and intelligent technologies.

To mention the Italian landscape, the first legislation on the use and implementation of BIM is very recent and only dates back to 2019, when the Italian Ministry of Infrastructure Paola De Micheli has introduced an initial plan for making BIM mandatory from 2019, but solely for projects above 100 million.

This is the first of a series of deadlines, ending with full implementation by 2022, when BIM will become mandatory for all public procurement projects. However, these decisions are still in the status of 'subject to review'. There is just one thing to be clear about: simple jobs can be carried out using traditional methods. For example, residential buildings with no particular safety issues.

The legislative text of reference is paragraph 13 of Article 23 of the new procurement code. This article explicitly states that "for new works, as well as for renovations, upgrades or variants, with priority for complex works, the contracting authorities may require the use of electronic methods and tools... such tools use interoperable platforms through non-proprietary open formats...".

This refers precisely to the “possibility” of using such software, and not to mandatory position, with the only restriction that it is not a tool that restricts competition between providers of technological solutions and designers.

The use of electronic tools can only be required by contracting entities if they have adequately trained staff. The same article of the Public Procurement Code also stipulates that "the manner and timing of the gradual introduction of the compulsory use of the above methods ... will be evaluated in relation to the type of works to be entrusted and the digitalisation strategy of the public administrations ...".

Overall, the level of BIM competence is still considered to be basic; with a few exceptions, the authorities, companies and professionals are currently unprepared.

For this reason, it is not possible to force compliance with BIM at the moment, but it is important to define the general rules of implementation.

3.3 Blockchain

Blockchain is a peer-to-peer (P2P) distributed data structure that allows transaction data to be recorded chronologically and stored securely in a sequence or chain of blocks using cryptography. A blockchain is essentially an encrypted digital ledger stored on a public or private network of computers.

Blockchains consist of nodes on these networks that use a common communication protocol; each node on the network stores a copy of the chain and a consensus mechanism is used to validate transactions to ensure the immutability of the chain, i.e. transactions cannot be altered. The details of a transaction are sent to the network for validation and verification when a new transaction is created. If the nodes agree that the transactions in the block are valid according to a governance protocol, the block is added to the blockchain and each node's copy of the blockchain is updated accordingly.

Blocks of data cannot be altered or deleted by a single actor once they have been assembled into a chain. No single party or intermediary manages the data, and all parties can see the entire data infrastructure. (Bashir, 2017)

Blockchain technology can be delineated along two critical dimensions: the degree of permissions granted to nodes within the chain and the level of anonymity afforded to these nodes. When the level of anonymity is heightened, we encounter public blockchains, wherein any individual can potentially partake in the blockchain, validating transactions while maintaining a copy of the ledger on their node.

However, public chains with unrestricted permissions (e.g., Bitcoin, Ethereum, Waves) confront challenges concerning privacy protection.

On the other hand, as the level of permissions required to access and validate transactions escalates, the issue of centralization arises, presenting a potential contradiction to the very essence of the blockchain concept itself. (Algan TEZEL, 2020) This predicament emerges because increased permissions may necessitate relying on centralized entities, thus compromising the decentralized nature that underpins the core philosophy of blockchain technology.

Striking a balance between anonymity and permissions becomes a crucial consideration in developing blockchain systems that align with the envisioned principles of transparency, security, and decentralization.

Blockchain possesses the capacity to exert a profound influence on prevailing business transactions within the construction industry. This influence stems from its integration with smart contracts, cryptocurrencies, and dependable asset tracking mechanisms. Consequently, practitioners and researchers are progressively delving into distributed ledger technologies (DLTs), specifically blockchain, as a prospective resolution to address numerous obstacles that impede the optimal performance of the Architecture, Engineering, and Construction (AEC) sector.

These challenges encompass the facilitation of transparent collaboration, the establishment of secure and traceable data storage and retrieval systems, the facilitation of seamless business transactions with a reduced incidence of disputes, and safeguarding privacy and intellectual property rights.

The potential of blockchain and DLTs in mitigating these issues has garnered heightened attention, prompting increased exploration and investigation into their potential applications in the context of the construction industry.

The image below, taken from (Algan TEZEL, 2020), provides a synoptic overview of the opportunities and challenges of blockchain in CI, briefly touching on some of the practical applications.

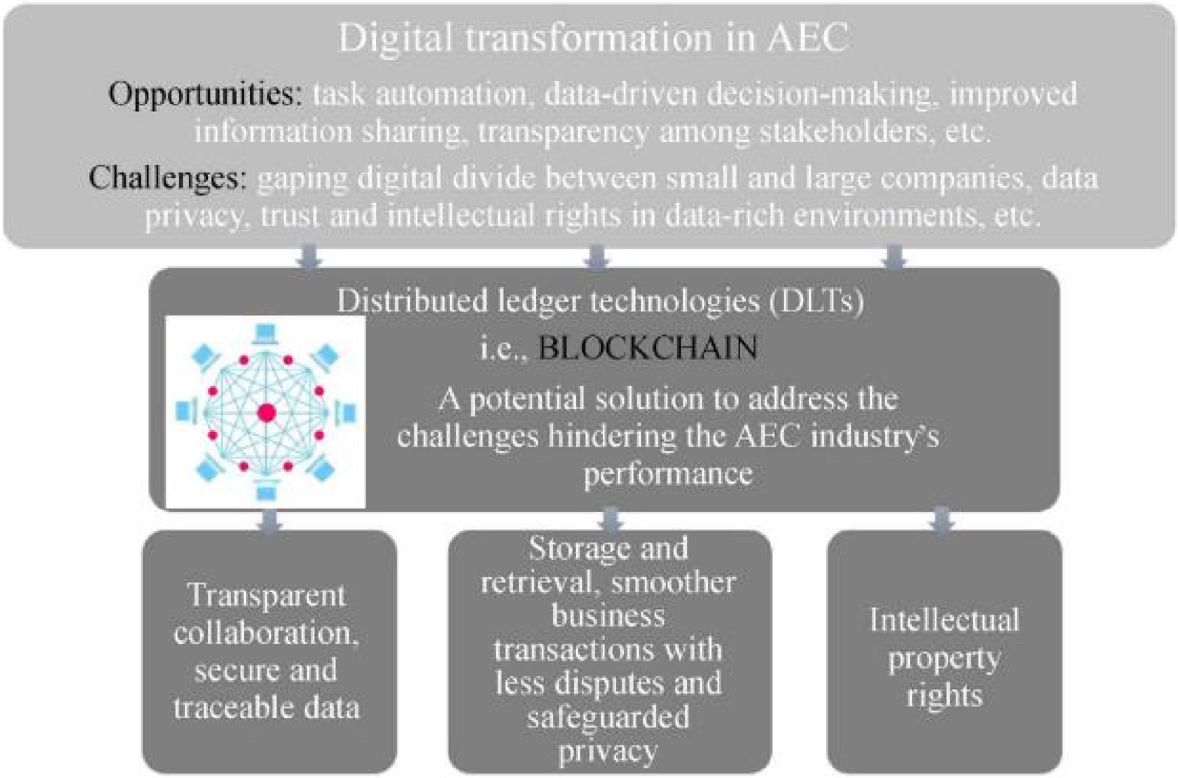


Figure 3.3.1 "Role of Blockchain technology in AEC industry".

Using primary data from expert interviews and secondary information from academic and grey literature, (Algan TEZEL, 2020) developed a SWOT analysis that can be used as a conceptual framework for preparing construction supply chains for blockchain.

The adoption of blockchain technology is poised to significantly impact various aspects of supply chain management (SCM), with the potential to facilitate key SCM objectives. Notably, blockchain's integration may lead to cost reduction through the streamlining of regulatory compliance costs and the elimination of financial intermediaries through disintermediation. Furthermore, its implementation can enhance speed by digitizing physical processes, bolster dependability through blockchain-based digital certification, and mitigate risks by allowing only mutually accepted parties within the network to engage in transactions.

Moreover, blockchain has the capacity to advance sustainability efforts by verifying and validating sustainable practices along the supply chain. Lastly, blockchain can enhance flexibility by providing a transparent and immutable proof of provenance for goods and services.

(Jennifer Li*, 2019) agrees with the idea that blockchain technology should not be used just because it is interesting, but that its application should be carefully studied. In fact, it is not a stand-alone solution, but merely a data infrastructure, a transparent layer underneath the transactions associated with those technologies, that can support the digital transition in conjunction with other technologies such as BIM and smart contracts.

(Klinc R, 2017) affirms that Blockchain has the capacity to address several critical issues and obstacles related to BIM. This includes concerns surrounding confidentiality, the removal of intermediaries, tracking provenance, aggregating inputs from multiple parties, maintaining records across different organizations, ensuring nonrepudiation, establishing traceability, determining data ownership and intellectual rights, and effectively tracking changes.

The study conducted by (Algan TEZEL, 2020) addressed the subsequent research query:

How can the construction industry effectively utilize the potential of blockchain technology throughout its supply chain? The study aimed to comprehend the significant advantages, drawbacks, potential opportunities, and challenges associated with the integration of blockchain technology in the construction sector.

From a technical perspective, the advantages are two-fold: enhancing the security of data storage and augmenting the traceability and transparency of data. On a sustainability front, secure procurement and payment processes, along with the ability to authenticate products and certificates of origin, also emerge as benefits. Moreover, blockchain has the capacity to foster the creation of decentralized shared data ecosystems. An example is the potential for blockchain-based cloud Building Information Modeling (BIM) platforms, serving as a trusted intermediary for bi-directional communication among organizations, cities, and regions. Consequently, blockchain stands poised to expedite the industry's digitalization agenda by surmounting substantial digitization hurdles tied to trust, transparency, data traceability, intellectual property rights, and record-keeping.

Conversely, weaknesses manifest in various aspects. These include a scarcity of skilled personnel in this domain, a dearth of commercially available frameworks, absence of legal regulations, and inadequate empirical evidence from a business-case perspective to substantiate the advantages of employing blockchain in Competitive Intelligence (CI). Some respondents highlighted that the true potential of blockchains is best harnessed through public blockchains, as private blockchains closely resemble distributed databases in terms of data security, rendering them susceptible to unwarranted data alterations and manipulation. Additionally, as blockchain technology proliferates, robust data validation systems and procedures will be indispensable within the industry, given the growing significance of data authentication.

As mentioned, several times throughout this literature review, the study of CI has revealed various inefficiencies and gaps. These issues are often attributed not only to inherent elements within the nature of CI itself, which may be difficult to change, but also to technological backwardness compared to many thriving industries that have experienced years of growth and advancement.

With this in mind, one of the main aims of the literature in this field, and consequently of this thesis, is to examine the various technological solutions currently offered on the market. The aim is to assess their potential impact on the industry and to map out possible future scenarios. This understanding can then be a guide for future research directions and investment decisions.

Distributed Ledger Technologies (DLTs) has though significant potential to support digitalization in the construction industry and address its challenges. However, before successful implementation, further investigation is required to assess the industry's readiness, organizations, processes, and necessary changes. (Jennifer Li*, 2019)

3.4 Different approaches

Although automation has been actively used in many industrial sectors since the second half of the 20th century, its application in the construction industry has been rare or not fully exploited. In their research, (Borja Garcia de Soto, 2017) et all set out to carry out a quantitative analysis in terms of cost and time between construction using traditional methods and construction using robots, a field known as digital fabrication (dfab). This term describes the combination of digital technologies and the physical construction process. In their analyses, they have focused only on cost and efficiency considerations, neglecting the aspect of environmental sustainability altogether. However, the social impact of dfab should not be underestimated, which according to (Cruz, 2019)'s view of the triple bottom line (environmental, economic and social) is a triplet of factors to be taken into account when talking about sustainability.

In fact, the use of robots to replace humans in repetitive jobs that require effort and fatigue should be seen as a step forward for a world that is moving towards the future.

Currently, the use of robots on construction sites is limited because the main solutions available on the market are so expensive that such an investment is not economically viable. Dfab techniques are based on the combination of computer-aided design methods and automated manufacturing processes, which are typically categorised as subtractive, formative or additive. Subtractive fabrication involves the removal of material using electrical, chemical or mechanically reductive processes (multi-axis milling). Formative fabrication uses mechanical forces, constraining moulds, heat or steam to reshape or deform a material. Finally, additive fabrication consists of the incremental aggregation of material layer by layer through extrusion, assembly, binder jetting, etc. In recent years, additive manufacturing processes, particularly 3D printing, have experienced rapid development in many industries. Additive construction consists of material aggregation through various techniques such as assembly, lamination and extrusion. Existing additive dfab technologies can be classified into two broad clusters: on-site and off-site construction technologies. (Borja Garcia de Soto, 2017) The off-site technology cluster can be seen as the use of larger, prefabricated components for use in construction.

Utilizing digital fabrication methods in the construction sector has the potential to greatly enhance productivity. This is primarily due to the substantial time saved when dealing with intricate designs. Additionally, the direct transfer of design data to 1:1 assembly tasks and automated construction further contributes to efficiency gains. However, it's essential to note that applying additive digital fabrication (dfab) to large-scale construction is still in its early stages. This approach encounters hurdles in terms of transforming conventional construction practices and redefining the roles of individuals involved in the projects.

Construction productivity refers to how effectively, swiftly, and economically buildings and infrastructure can be constructed (National Research Council, 2009). By analysing data collected from simulations (Borja Garcia de Soto, 2017), productivity metrics such as USD/m3 and Hrs/m3 were computed to quantitatively compare two wall construction methods: conventional and robotic fabrication.

For straightforward walls with low complexity, there seems to be no significant economic advantage in employing DFAB over conventional construction methods. However, the situation is entirely different for highly complex double curved walls. In such cases, the robotic fabrication process showcased higher productivity compared to the conventional approach when constructing intricate building elements. From these assumptions, the authors show how the use of dfab is favourable in terms of both cost and efficiency as the complexity of the structures to be built increases as it is shown in Fig 3.4.1 e 3.4.2.

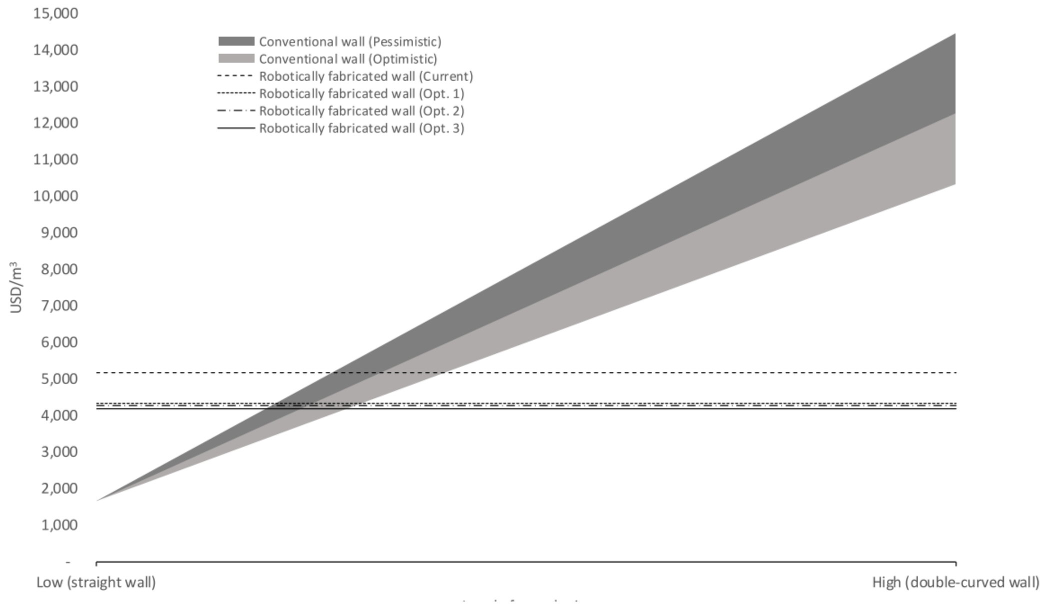


Figure 3.4.1 "Cost per installed quantity (USD/m3)"

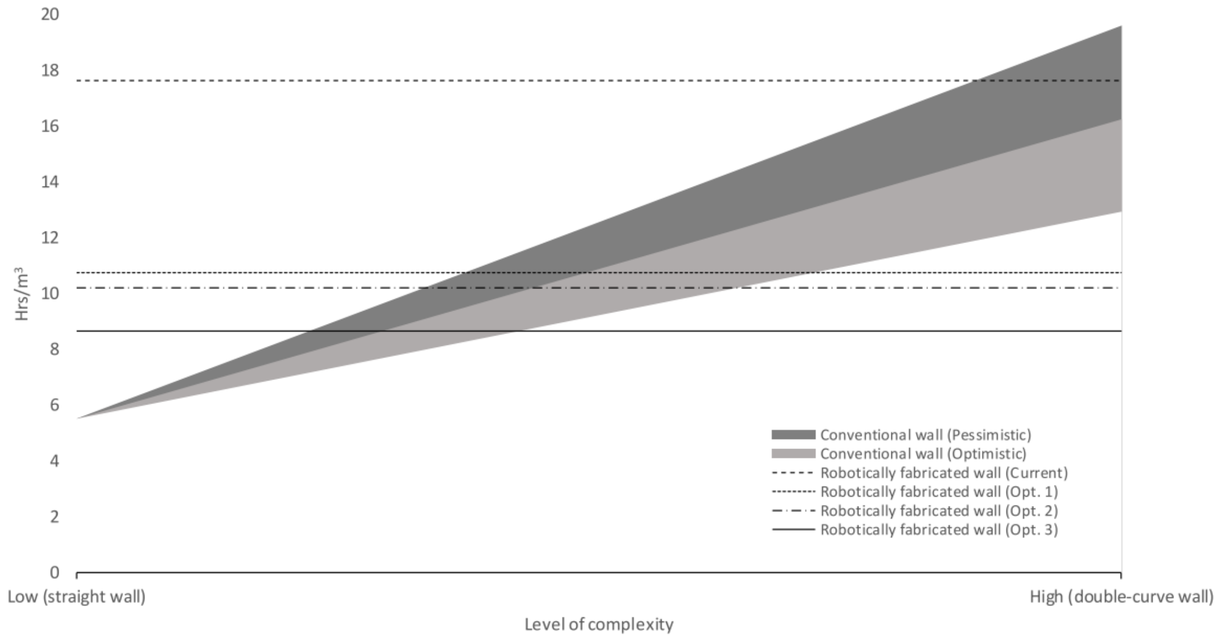


Figure 3.4.2 "Hours per installed quantity (Hrs/ m3)"

The experimental nature of the specific robotic system (IF) and the custom tooling needed for the construction process might considerably elevate project costs, rendering it impractical for commercial applications at present. Nonetheless, given the dynamic nature of this field and the current trends in robot prices, it is expected that commercial robots similar to the IF will become notably more cost-effective than the one utilized in this case study. Therefore, future robotic manufacturing techniques are projected to yield greater economic savings.

Furthermore, when considering more practical scenarios involving the construction of multiple structures (rather than just a single wall as seen in the case study), the cost of the robotic system is likely to become more competitive due to economies of scale, making robotic manufacturing a financially viable option. (Borja Garcia de Soto, 2017)

4.0 Sustainable Procurement Management

As societies around the world become more sensitive to the need to protect the environment and use resources responsibly, the concept of sustainable procurement management will be an important framework within the construction industry.

Sustainable procurement management encompasses a holistic approach that considers the environmental, social and economic impacts of every procurement decision. This shift in perspective recognises that construction activities have far-reaching impacts, such as resource depletion, greenhouse gas emissions, labour rights violations and community disruption.

Integrating sustainability into procurement strategies is therefore essential to aligning the construction industry with global sustainable development goals.

The choice of construction material sources holds significant importance in the management of construction supply chains. It has a direct impact not only on the transportation expenses and project timeline but also on the environmental footprint of the construction project.

In the CI, there is a considerable number of challenges that need to be identified and managed throughout the project lifecycle when materials and equipment are supplied to construction projects from sources outside the construction organisation.

To achieve circular economy goals in the construction industry, it is essential that all actors in the supply chain are involved and aligned with the goal of reducing environmental impacts.

The main players are undoubtedly the raw material suppliers; indeed, given the large volumes involved, the economic and environmental impact of the way these materials are produced, handled and transported is enormous.

Not all materials are supplied by the same supplier, so a large number of external actors need to be involved and aligned with SPM objectives; this requires supplier selection procedures and methods that are well established, stable and flexible enough to adapt to material suppliers with completely different characteristics and therefore logistical requirements.

As mentioned above, and as noted by (Krause, 2009) in their paper on Sustainable Supply Chain Management in the context of purchasing, it's necessary for all the actors involved to contribute, as they say:

"A company is not more sustainable than its supply chain".

Although each project has to be considered on its own merits; the main materials used in CI are as follows:

- Bricks and blocks: Bricks and blocks are commonly used in the construction of walls and other types of structures. They are typically made of clay, sand, or concrete.
- Cement: A key raw material used to make concrete. It is usually made from limestone, clay, and other minerals.
- Aggregates: such as sand, gravel, crushed stone and recycled concrete. Often used as a base layer for roads and foundations, these materials add strength and stability to the structure.
- Steel: which is used extensively in the construction industry for its strength and durability, such as for the reinforcement of concrete.
- Wood: Widely used in construction to frame, floor and finish. It is also used for decorative purposes, such as in furniture and in the design of interior spaces.
- Glass: used to make windows, doors and other architectural features. It is also used for decorative purposes and as a building material in its own right.
- Insulation materials: such as fibreglass, rockwool and foam, are used to improve the energy efficiency of buildings by reducing heat loss and gain.

The side-effects of non-compliance with sustainability principles by suppliers and contractors are not only environmental but can also have a negative impact on social and economic sustainability.

The traditional approach to sustainability in the construction sector is overly focused on the environmental dimension; today's needs require a broader vision that takes into account a wider range of factors in order to make effective decisions from a global perspective, that's why (Cruz, 2019) discusses the importance of considering all three dimensions of the well-known triple bottom line approach (environmental, economic and social).

Procurement management challenges in construction projects range from delays in the delivery of items to the provision of unsustainable equipment that may pose environmental risks; furthermore, the complex, multi-disciplinary nature of the construction industry limits the options available to procurement managers when making source selection decisions, due to constraints such as resource availability, lack of qualified subcontractors and resource commitment.

Another key factor is having a clear definition of the scope to be analysed when talking about selecting sustainable suppliers is to make a clear distinction between the private and public sectors, just as (Mahmoud Ershadi a, 2021) did in their research.

In the public sector, public policies and social values are often given more attention, with a greater focus on the interests of the whole community, whereas in the private sector, the main objective is to increase profits.

Another reason for the significant differences between the private and public sectors is that the public sector is supported by government in achieving these goals, whereas private companies have to rely on their limited budgets, undermining the efficiency of their economic resources and potentially eroding the returns to society.

As on the one hand the public sector is confronted with protecting the interests of taxpayers, authorities and bureaucracies; on the other hand, the private sector has more flexibility in decision making, but it faces conflicts in meeting the costs associated with sustainability objectives while making the profits necessary to sustain its business.

An interesting solution could be to require a minimum percentage of materials to be sourced from C&D waste in order to incentivise this business channel for companies in the sector and encourage the implementation of RLSC techniques. This again supports (Maria Ghufran 1, 2022)'s analytical framework that the CI framework needs to be considered from a systemic and ensemble perspective. In particular, the impact of the different actors on each other and on the system as a whole, for example, in this case, the impact of regulations on the incentive to use recycled sustainable materials from C&D waste.

(Sourani) explored challenges facing public organizations in the UK construction industry and identified 12 main barriers concerning lack of funding, lack of awareness, inconsistent policies, the vagueness of sustainability definitions, separation between capital budget and operational budget, lack of time to address sustainability issues, lack of long-term perspective, assuming sustainability as a greater capital cost, resistance to change, insufficient integration, and insufficient research and development.

Other challenges identified in the public sector include higher costs, poor policy, inadequate legislation, lack of technical guidance, ineffective controls, licensing issues and difficult access to technology.

With a focus on the private sector, it is important to introduce a new concept that underpins corporate initiatives that benefit the whole community: Corporate Social Responsibility (CSR).

This new concept has gained significant attention in recent years as companies strive to operate in a sustainable and socially responsible manner. CSR is based on the idea that companies have a responsibility not only to maximise profits but also to contribute to improving society and the environment.

As well as benefiting society and the environment, companies that embrace CSR often experience increased customer loyalty, employee satisfaction and long-term financial success.

Even though the increasing importance of corporate social responsibility in the private sector has promoted several research initiatives in this field; companies' proposals towards a circular economy are often driven more by economic interests related to public reputation and green washing rather than by shared ideals and environmental goals.

The concept of a sustainable supply chain began as a commitment to waste reduction, but corporate social responsibility has broadened the concept and led organisations to take a more collaborative approach to environmental supply chain management. In this dimension, sustainability principles should be embedded in all stages of the procurement, from product design to material sourcing and end of life management of the facility.

(Cruz, 2019) discusses the importance of considering all three dimensions of the well-known triple bottom line approach: environmental, economic and social and to consider the short to long term impact of a sustainability strategy, they also emphasize the operational, tactical and strategic dimensions.

On the base of these assumptions, (Mahmoud Ershadi a, 2021) focus on the distinction between internal and external barriers to the analysis of barriers to the strategies of SPM implementation. The practical contribution is to identify areas that need more attention from policymakers in order to adopt effective strategies to tackle barriers at both intra- and extra-organisational levels.

Internal barriers are characterised by operational and strategic processes, and the tools used by organisations to achieve sustainability goals. In contrast, barriers external to the organisation emphasise the role of stakeholders.

In order to present a complete picture of the state of the literature in the field of sustainable procurement, (Mahmoud Ershadi a, 2021) identified five key areas through which to filter the barriers and strengths of SPM: focusing on the intra- and extra-organisational aspect.

For this analysis, they used a case study based on a company within the Australian construction industry and interviewed 6 staff members as PMO leaders and project managers and planners with more than 10 years of experience in the industry. Finally, using the Nvivo software for systematic data collection and organisation, 10 main barriers were extracted and divided into 5 key dimensions based on the semantic relationships between them.

Barriers to sustainable procurement refer to obstacles in processes and structures that can lead to the failure to achieve the objectives of SPM in construction organisations. The identification of such barriers will help project managers to develop better strategies for the integration of sustainability into project delivery arrangements.

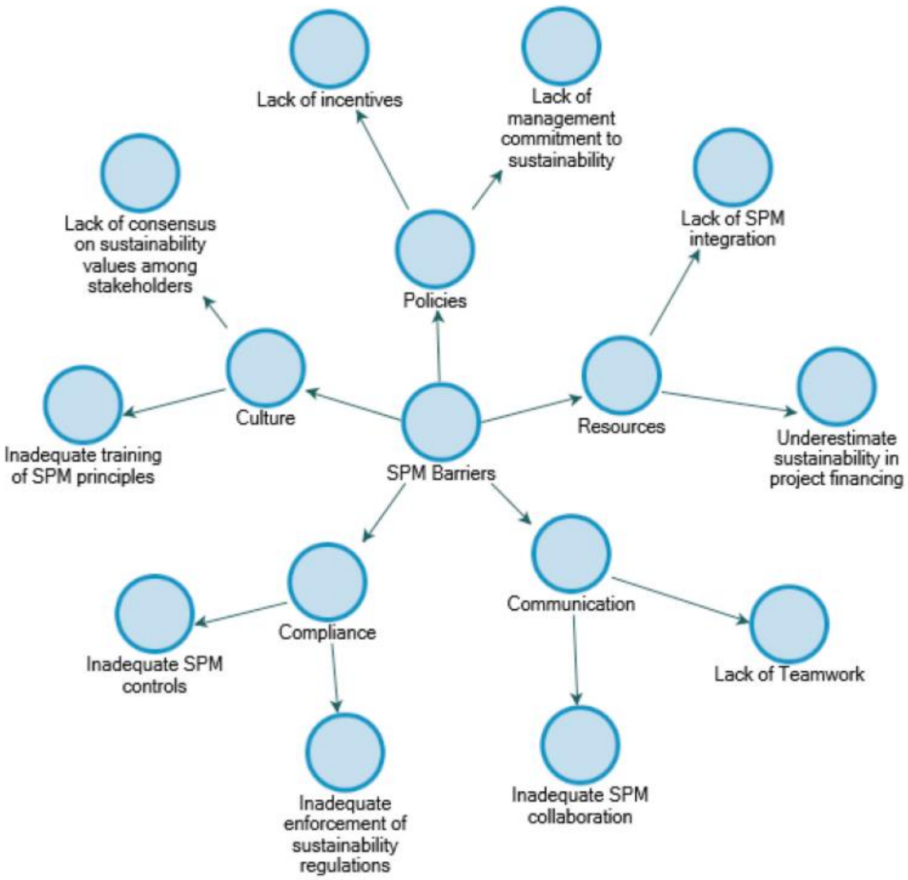


Figure 4.0.1 "Sustainable Procurement Management barriers"

As illustrated in **Figure 4.0.1,** the five key dimensions are: Policies, Resources, Communication, Compliance and Culture. For each dimension, an internal and an external barrier was selected.

With reference to the sphere of communication, the internal barrier is the lack of teamwork as experts believe that a robust tram that shares the ethical goals of the company is the trigger for synergies leading towards SPM.

On one hand, miscommunication and lack of trust can make the project deviate from the original procurement plans; while on the other hand, from an external point of view, the lack of integration between sustainability goals and operational and strategic activities for the procurement decision can lead to unsatisfactory outcomes.

As far as cultural aspects are concerned, internally the barrier is inadequate training in SPM principles. In fact, it is not enough for top management to make decisions for sustainability goals to be realised; but top management decisions should be followed by structured plans to involve the entire hierarchy.

Indeed, SPM goals can only be achieved if techniques and training pervade the entire organisation to the point of becoming a concrete reality in the day-to-day operations.

This conception, should also be reversed outside the company in the strict sense, in fact it is necessary that the consensus towards the pursuit of these objectives is shared at the level of the stakeholders; suffice it to say that shareholders or investors in general who do not believe in those ideals can easily move their capital towards more profitable companies in the short term, since as we have seen SPM requires large initial investments that can temporarily undermine profitability.

From a compliance point of view, and by compliance is meant the act of adhering to rules, laws, regulations, or standards set by a governing body, organization, or industry; the barriers are the lack of adequate controls.

Without control, in fact, it is not possible to evaluate ex post the behaviour and decisions taken in a given time frame, nor is it possible to take corrective measures to realign activities with strategic objectives.

Furthermore, the lack of regulations in this respect creates less pressure on compliance bodies to enforce the measures defined in the business plans. The same analysis applies to the lack of policies, which in general leads to a lack of objectives and commitment on the part of the management area.

According to figures **Figure 4.0.1**, there are some major roadblocks, like communication glitches and issues with following regulations due to not having good enough control systems to verify the provenance and sustainable attributes of materials. Respected scholars within the academic sphere assert that these precise facets hold the potential for resolution and fulfillment through the application of technological solutions. More specifically the incorporation of blockchain principles into the realm of "Smart contracts" could constitute a preliminary stride towards the establishment of innovative monitoring techniques and methodological frameworks.

4.1 Smart contracts

BIM is described as a precursor to smart contracts, with DLT providing a platform for them to operate, and where the two should be seen "as part of the BIM-led construction revolution, not separate from it". Smart contracts running on a DLT can lead to payment security, stabilising smaller contractors and increasing confidence in projects through the historical, immutable record of a distributed ledger. (McNamara, 2018)

Strengthening procurement and supply chain activities with smart contracts leads to automated payments, provenance tracking, contract management, disintermediation, ownership and control of data.

Payment, and in particular the timely payment of contractual claims, is one of the most significant dilemmas facing the construction industry. This issue is exacerbated by late payments, non-payments or undue delays due to disputes, which can often have disastrous consequences such as project failures, cash flow difficulties and mistrust. (Cardeira, 2015)

At the sustainability level, the assurance of material origin and adherence to sustainable sources and processes assumes paramount importance. This assurance is achieved through third-party guarantees that can be validated and certified via blockchain technology. This facet gains particular significance as it enhances transparency and accountability in supply chains, providing stakeholders with irrefutable evidence of sustainable practices and responsible sourcing of materials.

In contrast to conventional supply chains, blockchain-based supply chains involve the participation of four significant entities (Saberi S, 2019). These entities include:

1) Registrars: Registrars play a pivotal role in providing unique identities to the actors operating within the blockchain network.
2) Standard Organizations: These entities are responsible for defining standard schemes, blockchain policies, and technological requirements that govern the functioning of the supply chain.
3) Certifiers: Certifiers are instrumental in providing certifications to the actors within the supply chain network, which qualifies them for participation in the system.
4) Actors: This category encompasses a diverse range of participants, such as service providers, manufacturers, retailers, and customers, all of whom must undergo certification by a registered auditor or certifier. This certification process is vital for maintaining trust and integrity within the blockchain-based supply chain system.

With their innate characteristics of being immutable, secure, and traceable, smart contracts offer a collaborative working environment among clients, contractors, subcontracts, suppliers, and consultants. (Ernest E. Ameyaw, et al., 2023)

The integration of blockchain-based smart contracts holds significant potential for revolutionizing contractual transactions within various industries, including the construction sector. Smart contracts are self-executing agreements that automatically execute and enforce contract terms when predefined conditions are met. These contracts operate within the secure and transparent environment of a blockchain, a decentralized and tamper-resistant digital ledger.

In the realm of construction, where complex projects involve numerous stakeholders, intricate agreements, and intricate timelines, smart contracts offer a streamlined and efficient alternative to traditional paper-based contracts. By encoding contractual terms and conditions directly into the blockchain, smart contracts ensure precision and accuracy, reducing the risk of disputes arising from misunderstandings or misinterpretations.

Moreover, the automation provided by smart contracts can significantly enhance the efficiency of contract execution. These contracts are programmed to trigger actions automatically when specific conditions are fulfilled. For instance, once a contractor completes a designated phase of a project, the corresponding payment can be automatically released to them, eliminating the need for manual intervention and reducing delays in payment processing. This can be particularly advantageous in construction, where timely payments are crucial for maintaining the smooth progress of projects. (Ernest E. Ameyaw, et al., 2023) (Cardeira, 2015)

The use of blockchain-based smart contracts also addresses issues of transparency and trust in contractual relationships. As all parties involved have access to the same immutable and transparent ledger, disputes are minimized, and accountability is heightened.

This transparency reduces the need for intermediaries to oversee contracts and mediate conflicts, ultimately lowering administrative costs and expediting decision-making processes.

There are five critical factors that undermine all these benefits:

1. Technical Proficiency: Stakeholders need to learn smart contract programming for successful integration.
2. Trial Period: Testing smart contracts in non-critical areas before full adoption minimizes disruption.
3. Transparency: Establishing data-sharing protocols balances transparency with confidentiality.
4. Payments and Payouts: Integration challenges, currency conversions, and legal compliance must be addressed for smooth financial operations.
5. Security: While blockchain enhances security, vulnerabilities in code and cyber threats demand attention.

Navigating these factors requires a strategic approach that involves education, collaboration, and adaptable change management strategies. (Ernest E. Ameyaw, et al., 2023)

In final consideration, it must be recognised that DLT is not a solution in itself, but should be accompanied by developments in the legal, social and process dimensions.

Only in this way can the construction sector keep pace with the ongoing applications of DLT and other digital developments in the wider built environment on the rapidly evolving journey towards a 'smart' vision of the future.

Discussion e conclusion

Following the comprehensive analysis conducted, several key conclusions emerge. Foremost among them is the prevailing consensus within the literature that the intricate construction and infrastructure industry necessitates holistic scrutiny. Particular emphasis is placed on the pivotal role of external stakeholders and socio-political variables, which wield substantial influence over the profitability and strategic direction of companies in this sector.

Upon establishing that the scope of inquiry extends beyond the confines of individual companies, this study proceeds to delineate the primary areas of investigation addressed herein, pinpointing the gaps between them, and shedding light on the trajectory for future research in this domain.

In light of the industry's imperative shift toward sustainability, meticulous management of material flows emerges as a critical imperative. Given the substantial material requirements for constructing buildings and infrastructure, efficient resource management directly translates into reduced transportation costs and diminished CO_2 emissions. Achieving this necessitates enhanced flow mapping precision and more seamless integration of information and business processes across project phases.

In this context, the words of renowned physicist and engineer Lord Kelvin resonate: "What cannot be measured, cannot be controlled," underscoring the fundamental role of measurement in process and system management.

The literature advances Building Information Modeling (BIM) and its various integrations with software such as Geographic Information Systems (GIS) and Warehouse Management Systems (WMS) as the tools of choice to address these imperatives. These technologies offer not only material tracking capabilities but also facilitate material reordering and movement within the supply chain. The integration of all software and program layers used throughout the lifecycle of a construction project is deemed essential for reducing information disparities and ensuring the uninterrupted flow of current information. Moreover, BIM's digital representation of the design, construction, and operational phases fosters improved collaboration and communication among diverse stakeholders.

Another inefficiency plaguing the sector results from miscommunication and trust deficits in supply contract execution, often leading projects astray from their original procurement plans. A viable remedy emerges in the form of smart contracts, which are blockchain-based applications designed to enhance contract efficiency. Blockchain's decentralized and immutable nature ensures transparency and traceability throughout the supply chain, effectively mitigating issues like delays and disputes arising from information discrepancies. However, this innovation must be complemented by advancements in legal, social, and procedural dimensions.

Experts in the industry perceive these innovations as a pivotal step towards sustainability, although most academic articles primarily comprise surveys of industry experts. These innovations represent the initial strides towards a sustainable transition, with a significant gap in the literature concerning the presence of ample real case studies that can serve as benchmarks to validate the improvements these tools promise.

As for smart contracts, a preliminary testing phase in non-critical areas is recommended before widescale adoption to pre-empt potential disruptions.

Given the substantial generation of end-of-life waste within the construction sector, where only 20-30% is currently reused, the concept of 'Selective Demolition' is introduced as a potential solution. This entails a series of activities aimed at preserving the integrity of components subject to demolition. Realizing this transformation necessitates the redesign of systems and processes, alongside the establishment of a secondary market for used components.

However, the literature currently lacks a foundational framework for comprehending the dynamic socio-political context that underpins reverse logistics in the disposal and remediation of construction and demolition waste.

It's important to note that inadequate or absent legislation presents a significant global barrier to effective waste management.

Hence, one of the research's crucial findings underscores the need for political and governmental support to bridge the gaps in this sector. Such support should encompass a suite of incentives to facilitate a sustainable revolution within the construction and infrastructure industries. Future research may delve into the correlation between policies and legislation in different national contexts within the construction industry, examining their impact on the adoption of innovative and intelligent technologies.

Bibliography

Agarwal, R. C. (2016). Imagining construction's digital future.

Algan TEZEL, E. P. (2020). Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions.

Ballard, G. (1997). Lookahead planning: the missing link in production control. *Proceedings of the 5th Annual Conference of the International Group for Lean Construction (IGLC-5*, 13-26.

Bashir, I. (2017). Mastering Blockchain.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. Automation in Construction.

Borja Garcia de Soto, I. A.-J. (2017). Productivity of digital fabrication in construction: cost and time analysis of a robotically built wall.

Cardeira, H. (2015). Smart contracts and possible applications to the construction industry'.

Carter, C., & Ellram. (1998). L.M. Reverse logistics: A review of the literature and framework for future investigation. 85-102.

Cruz, C. G. (2019). OnOn the concept of sustainable sustainability: an application to the Portuguese construction sector. *Journal of building engineering*.

Dat Tien Doan, A. G. (2020). Examining critical perspectives on Building Information Modelling (BIM) adoption in New Zealand. *Emerald Insight* .

Dias, B. D. (2018). Regenerative development – building. *J. of Design & Nature and Ecodynamics. Vol. 13*.

E. Elbeltagi, M. D. (2011). Integrated visualized time control system for repetitive construction projects,. *Autom. Constr*, 940-953.

Edirisinghe, R. a. (2015). Comparative Analysis of International and National Level BIM Standardization Efforts and BIM Adoption. *2nd W78 Conference 'Applications of IT in the Architecture, Engineering and Construction Industry*.

Ernest E. Ameyaw, P., David J. Edwards, P., Bimal Kumar, P. M., Niraj Thurairajah, P., De-Graft Owusu-Manu, P., & and Goodenough D. Oppong, P. (2023). Critical Factors Influencing Adoption of Blockchain-Enabled Smart Contracts in Construction Projects.

F.F.A. Ahmadian, A. A. (2016). Accounting for transport times in planning off-site shipment of construction materials. . *Constr. Eng. Manag.*, 142.

Govindan, K., & Bouzon, M. (2018). From a literature review to a multi-perspective framework for reverse logistics barriers and drivers. *J.Clean*.

Gu, N. S. (2014). BIM Ecosystem: The Coevolution of Products, Processes, and People. In Building Information Modeling: BIM in Current and Future Practice. 197.

H.P. Tserng, S. Y. (2006). Developing a resource supply chain planning system for construction projects. *J. Constr. Eng. Manag.*, 393-407.

Harvey M.Bernstein, B. M. (2014). McGraw Hill (2014), The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation with Building Information Modeling, SmartMarket Reports. Retrieved 03 January 2015. *McGraw Hills*.

Hauschild, M. Z. (2015). Better – but is it good enough? On the need to consider both eco-efficiency. *ScienceDirect*.

Heaton1, R., Hector Martin, M., Aaron Chadee, M., Milling4, A., Dunne5, S., & Borthwick6, a. F. (2022). The Construction Materials Conundrum: Practical Solutions to Address Integrated Supply Chain Complexities. *ASCE*, 15.

Jennifer Li*, D. G. (2019). lockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases.

K.R.A. Nunes a, C. M. (2009). Reverse logistics in the Brazilian construction industry. *Journal of environmental management*.

Kaza S, Y. L.-T. (2018). What a waste 2.0: a global snapshot of solid waste management to 2050.

Kenley, R. H. (2016). BIM Interoperability Limitations: Australian and Malaysian Rail Projects. *4th International Building Control Conference 2016*.

Klinc R, D. M. (2017). Role of blockchain in BIM systems. *The 3rd International Conference on Civil and Building Engineering Informatics*.

Krause, D. V. (2009). Special topic forum on sustainable supply chain management: introduction and reflections on the role of purchasing management. *J. Supply Chain Manag*, 18-25.

M.R. Sousa Matos, Y. F. (2018). Green vehicle routing and scheduling problem with split delivery. *Electron Notes Discrete Math*, 13-20.

Madduma Kaluge Chamitha Sanjani Wijewickrama 1, *. a. (2021). Minimizing Macro-Level Uncertainties for Quality Assurance in Reverse Logistics Supply Chains of Demolition Waste. *sustainability MDP*.

Mahmoud Ershadi a, *. M. (2021). Barriers to achieving sustainable construction project procurement in the private sector. *Cleaner Engineering and Technology*, 11.

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in costruction and demolition waste management. *Elsevier*.

Maria Ghufran 1, K. I. (2022). *Circular Economy in the Construction Industry: A Step towards Sustainable Development.* buildings.

McNamara, A. a. (2018). 'Barriers and drivers of Intelligent Contract implementation in construction'.

Melissa Chan a, *. H. (2022). *Developing an innovative assessment framework for sustainable infrastructure development.* Journal of cleaner production.

Odusami, K. T. (20008). Factors Affecting The Accuracy of Pre-Tender Cost Estimate in Nigeria. *RICS Construction and Building Research Conference*.

Patrick Dallasega, E. R. (2017). Sustainable Construction Supply Chains through Synchronized Production Planning and Control in ETO Enterprises. *sustainability*.

Po-Han Chen, T. C. (2019). A BIM-WMS integrated decision support tool for supply chain management in construction. *Elsevier*.

Rayra Brandao, M. R. (2021). Public administration strategies that stimulate reverse logistics within the construction industry: a conceptual typology. *Emerald*.

Ruwini Edirisinghe, K. L. (2015). Comparative Analysis of International and National Level BIM Standardization Efforts and BIM adoption. *conference paper*.

S. Pantini, L. R. (2020). Is selective demolition always a sustainable choice'.

Saberi S, K. M. (2019). Blockchain technology and its relationships to sustainable supply chain management. . *International Journal of Production Research*.

Song Wu, G. W. (2014). A TECHNICAL REVIEW OF BIM BASED COST ESTIMATING IN UK QUANTITY SURVEYING PRACTICE, STANDARDS AND TOOLS. *Journal of Information Technology in Construction*.

Sourani, A. &. (n.d.). Barriers to addressing sustainable construction in public procurement strategiesed.^eds. *Proceedings of the Institution of Civil EngineersEngineering SustainabilityThomas Telford Ltd*, 229-237.

Sruthi Suresh Babu, S. E. (2021). Material flow in construction sites – a case study. *Sustainability, Agri, Food and Environmental Research: Vol. 12* , 10.

Syed Uzairuddin ⥣, M. J. (2022). Digital monitoring and modeling of construction supply chain management scheme with BIM and GIS: An overview. *Elsevier*.

Thomas B. Christensen, M. R. (2022). Closing the material loops for construction and demolition waste: The circular economy on the island Bornholm, Denmark. *Elsevier*.

Thomas, H. R. (2005). Fundamental principles of site material management. *J. Constr. Eng. Manage*.

Tomáš Mandiˇcák *, P. M. (2021). Impact of Information and Communication Technology on Sustainable Supply Chain and Cost Reducing of Waste Management in Slovak Construction. *sustainability*, 19.

Tomáš Mandiˇcák *, P. M. (2021). Impact of Information and Communication Technology on Sustainable Supply Chain and Cost Reducing of Waste Management in Slovak Construction. *Sustainability MDP*.

Zhang, C. L. (2021). DfMA: Towards an Integrated Strategy for a More Productive and Sustainable Construction Industry in Australia. *sustainability*, 21.

Ellen MacArthur Foundation. (2013). TOWARDS THE CIRCULAR ECONOMY: Economic and business rationale for an accelerated transition. https://emf.thirdlight.com/link/x8ay372a3r11-k6775n/@/preview/1?o

Ellen MacArthur Foundation. (2013). TOWARDS THE CIRCULAR ECONOMY: Economic and business rationale for an accelerated transition. https://emf.thirdlight.com/link/x8ay372a3r11-k6775n/@/preview/1?o

https://irpcdn.multiscreensite.com/8bbcaf75/files/uploaded/Managing%20Complexity%20in%20Construction%20Projects.pdf

https://www.itconvergence.com/blog/6-key-benefits-of-just-in-time-inventory-management/

https://cobuilder.com/en/bim-in-italy/

https://www.ediltecnico.it/51786/bim-obbligatorio-2019-decreto/

https://www.codiceappalti.it/DLGS_50_2016/Art__23__Livelli_della_progettazione_per_gli_appalti,_per_le_concessioni_di_lavori_nonch%C3%A9_per_i_servizi/8390