Building Information Modeling and Radio Frequency Identification Integration for Construction Operation Workflow in Supply Chain

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Introduction

This report aims to explore and evaluate the integration of Building Information Modeling (BIM) and Radio Frequency Identification (RFID) technologies to enhance efficiency within the construction supply chain and aims to address the issue of the project workflow in concrete casting of the structural work during the construction phase. By focusing on these two core Construction 4.0 technologies, the report aims to identify practical methods of optimizing material tracking, coordination between stakeholders, and real-time inventory management on the construction site.

BIM and RFID represent a powerful combination capable of streamlining construction workflows by reducing material delays, improving logistical transparency, and supporting proactive decision-making. The relevance of these digital tools lies in their ability to address longstanding challenges in construction project execution, including supply chain bottlenecks and inefficient communication. Through a comprehensive analysis of a real-world construction scenario and a systematic literature review, this report will demonstrate how implementing BIM-RFID systems can significantly improve overall project efficiency, minimize downtime, and facilitate seamless coordination between supply chain actors.

Construction Project Description

The ICON Park residential building project is the chosen case study for the technical report, based solely on the practical experience of the author. The following subsections of this chapter present the project's primary information, followed by the contextual background of the problem statement.

2.1 Primary Information of the Project

The ICON Park was a real estate housing development based in Phnom Penh, Cambodia. Located in the Prek Eng district, the housing development was in one of the country's fastest-growing areas, where a complete community was located, including hospitals, schools, restaurants, retail stores, and many entertainment centers. This project comprised various contractors for geotechnical tasks, design processes, structural work, MEP, and electrical work throughout the design, construction, and operation phases. The budget for the entire project was concealed by the owner of the construction scheme; however, the approximate funds for the work package that the author's project team was tasked, ranged between 1 and 2 million US Dollars. The housing development project was finalized and ready for the real estate market in 2021.

The construction plot in Figure 2.1 covered an approximate area of 6 square kilometers and consisted of a series of interconnected villas, which merged together to form a vibrant micro-living neighborhood. The architectural design, along with a detailed render of the building's front elevation, is showcased in Figure 2.2.

Figure 2.1: Satellite aerial image of the site plot (Google Earth)

All of the homes in the complex were designed to be identical, as illustrated in Figure 2.3. Every villa was 7 meters by 11.30 meters in length, taking up a total area of approximately 89 square meters. Inside, every dwelling has three nicely furnished bedrooms, four modern bathrooms, a spacious living room, a well-stocked kitchen, and a parking lot, placed in a carefully planned manner to provide comfort and convenience to their occupants.

Figure 2.2: Elevation plan of the building (ICON Park)

Figure 2.3: As-built structure (Google Maps)

2.2 Contextual Background of the Problem

In this section, the problem context is addressed and explained based on the real-life situation, and the precaution of the issue on a larger scale is visualized, coupled with potential technologies that can be possibly integrated to tackle to issue.

During the progress of the construction projects, the continuation of the work as per the schedule was dependent on the availability of materials. Assuming all other factors were favorable, the supply of materials at the site was directly linked to the advancement of the work. In one of the team members' experiences with the project, he faced the same problem of not having sufficient materials to execute the slab construction and had to stop the work for the day. Upon the analysis and examination, he identified the cause for the lack of inventory stock was caused by the communication gap between the project manager and the supplier, and the improper estimate of the material before construction.

For any building project, keeping a close eye on levels of inventory stock days prior to major milestone occurrences is essential. With foresight, if materials are low, there is plenty of time to reorder and restock. This is especially important in fast-paced construction environments, where time is of the essence; just one day of downtime can lead to significant impacts on both costs and overall quality. In this particular project case, the lack of communication about material stock delayed the construction and forced the project manager to grant a paid day off to all the construction workers supposed to work on the slab construction. The issue itself significantly affects a medium-sized project like his, illustrating the potential consequences it could pose for mega constructions, which cannot be overlooked. Analyzing the situation with deeper insight is essential for suggesting necessary improvements in the future and avoiding the loss of a project for which the technologies of construction 4.0 possess the potential to be integrated, like Radio Frequency Identification (RFID), Drone Technology, Building Information Modeling (BIM), Unmanned Aerial System (UAS), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT), and many more.

Problem Definition

In this chapter, a detailed explanation, supported by statistics and research articles, of a specific problem that is intended to be solved using Construction 4.0 technologies is presented.

Raw materials can be identified as a major component in the construction industry [1]. There is no way to construct the final product without the material. To ensure the availability of required materials to perform a scheduled task, a proper system has to be established. According to an article by Rich Uphus [3], about 40% of the construction industry experienced delays due to supply chain bottlenecks. One of the major causes of job-site loss of productivity is a lack of materials when needed [4]. This is the exact problem we faced during our work, where we had to send many of our construction workers back home as we lacked the materials. This causes an indirect increase in the overall cost of the project, also delaying the work by many days because of which affects the overall scheduling of the project. This study considers 'Unavailability of material On-site' as the core problem with a plot of slab construction during the project. In our case, lack of supervision over the inventory without real-time material tracking, lack of proper communication between the inventory manager and contractor, and lack of information flow are the major causes of this problem, causing the loss of money and time along with the interruption in workflow.

3.1 Problem Quantification

In this section, the problem quantification was done by a selection of relevant research articles and a review of the literature. It is to explain why the stated problem is critical to the success of the case project and forecast the influence on the total cost and duration of the project via the existing research paper.

According to Awaad. S. et al. (2024) [4], it was stated that the lack of materials available was the main cause of disrupting the workflow and reducing project productivity. They also found that the major reason behind encountering this problem was a lack of structured communication and clearly defined tasks in the material management system. Divergence from the design, failure to coordinate and combine multiple functional specializations, and untimely communication cause higher division of the project into fragments, which were even more difficult to handle, causing hindrance in proper material ordering, delivery delays hike the project cost. Their research developed the material supply chain framework to ensure that the supplies and demand meet on time, but the real gap lies in the automation of the system. There always lies the human error and psychological area as the barrier that we attempt to overcome by the integration of BIM and RFID technology of construction 4.0.

Furthermore, Khursheed, S. et al. (2024) [5] studied the role of material management in construction projects, focusing on both qualitative and quantitative aspects that contribute to project delay, and found that limited supplier availability, low utilization of technology, and delayed material delivery cause poor material management. They also suggested integration of technologies in the system to improve communication and enhance material flow, and alignment between material planning and scheduling to ensure material demand is accurately synchronized with the planning and scheduling of the project. But he fails to explain the technologies and their integration, allowing us to work on BIM and RFID to overcome the recommended challenges.

Next, Carvalho, A. B. et al. (2021) [6] identified the cause of delay in the construction project where 12 factors were corelated to 4 delay factors amounting to 69.18% as supply management (21.41%), workforce management (20.79%), project management (17.64%) and climatic factors (9.34%). Here, through this, we can know that supply management and workflow management combined cause over 40% of overall project delay, which are interconnected to each other. This study states the magnitude of impact that the material supply can exert in the construction project. Thus, this problem should be accounted for analysis and integration of BIM and RFID to keep track of material along with a systematic supply chain management, which can overcome two-fifths of the delay in a construction project.

Subsequently, A.H.M.C.P, A. et al. (2020) [7] also quantifies the importance of material management in the construction project and stated that ‘ The construction industry is a highly material-intensive industry that requires a constant supply of materials during the entire construction period.’ According to this research paper, the current mitigation methods are not enough to give the effective solution to this problem and conducted the survey to reveal proper logistic planning, proper material handling, complete design are highly recommended mitigating measures which can be achieved by the Integrated system of BIM to perform scheduling and estimate the material requirement with the RFID to keep constant tract of the material in the inventory and a cloud data processing system to automate the demand order and restock the inventory.

Additionally, Al-Aidrous. et al. (2022) [8], signifies that the time and money constraint of the project are directly affected by the inventory management system. They conducted the two step methodology to identify critical impacts of inventory management and procurement and found communication between labour and management, information sharing, lack of software usage for tracking material, purchasing plan, and construction progress monitoring to be five major issues for delayed projects. They recommended we use the outcome of this research to develop the mitigating plans, where we came up with the concept of designing the system capable of cutting off voluntary communication by automizing the decision, strong construction 4.0 material tracking technology, and proper monitoring of the work progress with BIM technology.

Last but not least, Zeng, N. et al. (2024) [9] proposed the closest solution to ours by integrating 4D BIM technology with Kanban Batch to keep track of the materials and logistics and trigger the ordering of the material. As a conclusion of their case study of the river remediation project, they suggested digital collaboration of BIM with another platform can be the ultimate solution to achieve proactive construction logistics management. We decided to go with RFID technology over the Kanban system to have real-time data and monitoring over the inventory. RFID technology allows accurate tracking of the material and number efficiency due to individual RFID tags rather than cardboard or visual notation used in a kanban system.

3.2 Problem Tree Analysis

As a summary of the literature review conducted, we can see the bigger picture of the consequences that a lack of material in inventory due to poor inventory management and supervision can cause to the construction project. Much of the recent research has suggested improvement in supply chain management and inventory management to be done using new technologies of Construction 4.0 for an effective and automatic system, lowering the area of human error and responsibility. The authors have quantified the problem and have given the mitigation measures as well, but lack a clear system development idea using the technologies. The figure below is the problem tree analysis explaining the problem, its cause, and the effect.

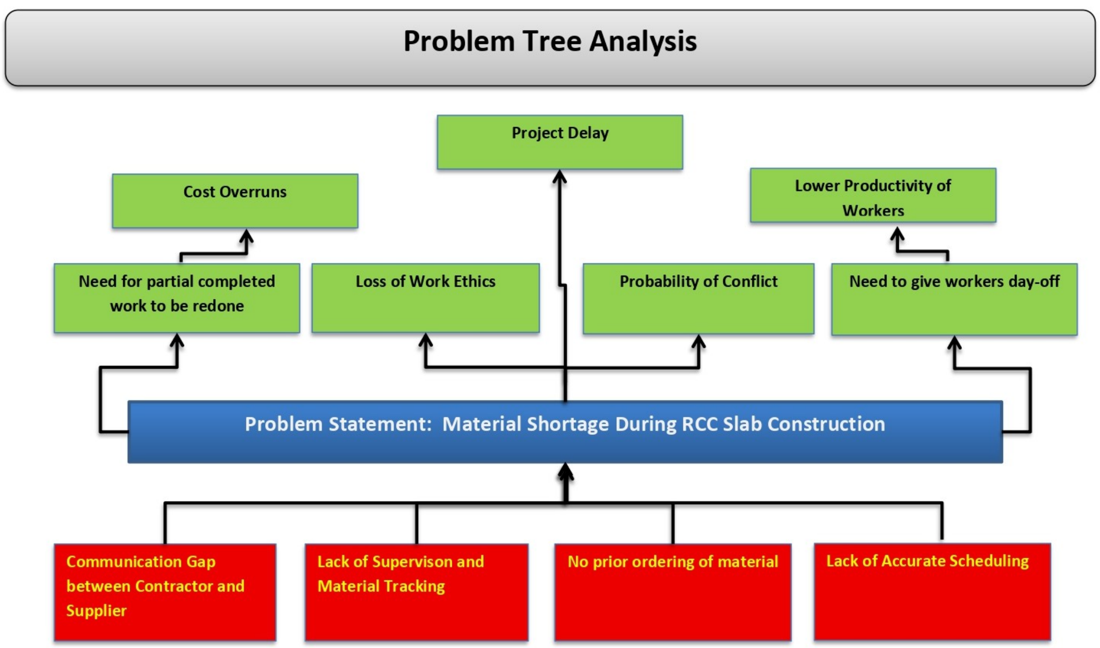

Figure 3.1: Problem tree of cause and effect (Author's illustration)

Core problem: Material Shortage during RCC slab construction.

The main problem addressed in our experience is the lack of cement and rebar while starting the slab construction work. The work was scheduled as per the project plan, and the prior work was going as per the plan, but nobody took into account the inventory status to inform the supplier about the possibility of material shortage at the site prior to the work commencement.

Causes:

- **Communication gap between the contractor and the supplier:** The contractor was not able to place an order for the materials on time, due to which the supplier had no idea when to send the next batch or in what quantity.
- **Lack of supervision and material tracking of inventory:** The inventory manager was not responsible enough to check the material quantity available and prepare the demand sheet for ordering materials.
- **No prior ordering of material:** There was no proper technological consideration for forecasting material requirements.
- **Lack of proper scheduling of work:** Scheduling work without having inventory information reflects a poor scheduling process.

Effect:

- **Project delay:** Lack of materials on site causes scheduled work to be held up, resulting in additional time requirements for the overall construction process.
- **Cost overruns:** Additional costs arise from retaining machinery, equipment, and labor, leading to direct cost overruns.
- **Lower productivity of workers:** Workers waiting for materials without being able to work leads to reduced labor productivity.
- **Need for partially completed work:** If material shortages occur during block construction, the work may need to be redone to maintain quality standards, increasing waste production.
- **Loss of work ethics:** Assigning labor and later sending them away due to lack of materials can lead workers to question the project's professionalism and ethics.
- **Probability of conflict:** Different parties may start blaming each other, leading to conflicts that can halt the project for a period of time.
- **Need for emergency supply order:** Unavoidable work may force the project to invest more in urgent material procurement, potentially causing vendor conflicts and unnecessary cost increases.

Construction Scenario

This report, as mentioned earlier, explains the construction scenario on ‘Improvement of Workflow’. The justification includes the management of the supply chain throughout the project and constant supervision of the inventory status so that none of the construction activities had to be stopped or postponed due to the unavailability of material. From the justification by literature review, the cause of material shortage caused by communication gap and lack of supervision has a greater influence on overrun of cost and time of the construction, making any project manager adopt the construction 4.0 technology to ensure the inventory stock is maintained automatically and restocking is done in a timely manner.

This solution together maintains the workflow and smooth progress of all the projects. The aim of this system is to enhance the productivity of workers, reduce the financial loss of the project, and accomplish the task on time as per the schedule without any hindrance.

Resolution Design

This chapter discusses a feasible solution to the problem outlined in this study, with key performance indicators (KPIs) identified in Section 5.1. Additionally, it introduces Construction 4.0 technologies that facilitate the detection and evaluation of the KPIs. Following this, a comprehensive literature review has been conducted to validate the implementation of these digital pipelines. Finally, the justification addresses the defined problem and discusses its anticipated implementation benefits.

5.1 Identification of Key Performance Indicator

5.1.1 Material Availability

This KPI measures the coordination between the current material availability on site and the planned requirements outlined in the BIM model. Using RFID technology, materials can be tagged and tracked in real time, enabling automated inventory checks. BIM provides a detailed schedule and quantity of material needed at every construction phase, and comparison with RFID-based real-time inventory gives an accurate measure of availability. It is to make sure that neither material is short nor in excess, avoiding delays and storage costs, and enabling active control of material flow, particularly for just-in-time delivery systems.

Formula:

$$\text{Material Availability (\%)} = \left(\frac{\text{Number of required materials available on-site}}{\text{Total number of materials required (per BIM schedule)}} \right) \times 100 \tag{5.1}$$

Where:

- Number of required materials available on-site = Quantity of materials (as identified by RFID) that are currently present and match the BIM-planned requirements for the current construction phase.
- Total number of materials required = Quantity of materials that should be available at the current stage according to the BIM schedule.

Interpretation:

- 100% = All required materials are available; ideal condition.
- $<$100% = Some required materials are missing, risking schedule delays.
- $>$100% = More materials than required are available; possible overstock or early delivery, which may increase storage costs or create clutter.

Frequency: Real-time

Data source:

- RFID tag readings from site or warehouse
- BIM model (inventory data and schedule)
- Material inventory management system

Data requirement:

- Unique ID for each RFID-tagged material
- Location and timestamp of RFID scans
- Planned delivery and use schedule from BIM
- Current inventory levels

Information requirement:

- Which materials are currently available on-site
- Whether these materials match the ones required by the BIM schedule
- Real-time availability data vs. required material list

5.1.2 Supplier Reliability

This KPI gauges suppliers' performance against how regularly material is delivered to the intended schedule from BIM, with the use of RFID tags to precisely timestamp upon delivery. By relating the actual delivery time to the intended dates, this KPI determines the suppliers' reliability, which is vital for compliance with the construction schedule. It also indicates the confidence level of the supplier in how reliable the supplier is. Delays in the delivery of materials can postpone critical tasks and lead to cost overruns for the project, and hence, this KPI helps in making strategic decisions in supplier selection and contract adherence.

Formula:

$$\text{Supplier Reliability (\%)} = \left(\frac{\text{Number of on-time deliveries}}{\text{Total number of deliveries}}\right) \times 100 \tag{5.2}$$

Where:

- Number of on-time deliveries = Deliveries that arrived within the planned time window defined in the BIM schedule.
- Total number of deliveries = All deliveries made by the supplier during the evaluation period.

Interpretation:

- 100% = All deliveries were made on time; highly reliable supplier.
- <100% = Indicates inconsistency or delays; potential risk to the project timeline.

Frequency: Weekly

Data source:

- Supplier delivery logs
- RFID scan timestamps at delivery points
- BIM procurement schedule

Data requirement:

- Delivery timestamps
- RFID tag data for material verification
- Required delivery timelines from BIM
- Supplier identification per shipment

Information requirement:

- Whether delivered materials meet the schedule requirements
- The supplier responsible for each batch
- Identification of delays and trends in delivery performance

5.1.3 Schedule Adherence

Schedule adherence measures the actual progress of the work done on the construction site against the planned progress as laid out in the BIM model. With BIM 4D (time-associated) models, the project managers can create a visual and data-based estimate of task orders and durations. RFID and other IoT applications can validate material installations and task completions so that real-time feedback data can be utilized to measure realized progress. The idea of the system is to avoid unexpected order and to reduce the improvisation of material order. This KPI enables the project manager to get early indications of schedule slippage, an explicit measure of project productivity, and an indicator of potential work restrictions due to staff issues, delayed material delivery, or unexpected site conditions.

Formula:

$$\text{Schedule Adherence (\%)} = \left(\frac{\text{Actual Progress}}{\text{Planned Progress}}\right) \times 100 \tag{5.3}$$

Where:

- Actual Progress = The percentage of tasks or work packages completed on-site at a given time, validated using RFID scans, IoT sensors, or manual inspections.
- Planned Progress = The percentage of tasks that were scheduled to be completed at the same point in time, as defined in the BIM 4D model.

Interpretation:

- 100% = Perfect adherence; construction is progressing exactly as scheduled.
- $>$100% = Ahead of schedule.
- $<$100% = Behind schedule, indicating potential delays.

Frequency: Monthly

Data source:

- BIM 4D model (planned schedule)
- Site progress tracking (RFID for materials installed, manual inspections, or sensors)
- Construction management platform

Data requirement:

- Planned vs. actual start/end dates for each task
- Installation confirmation using RFID or other progress capture tools
- Work package IDs and task breakdowns

Information requirement:

- Disparity between planned and actual progress
- Reasons for deviation (e.g., delays in material delivery or workforce availability)
- Forecast for upcoming progress adherence

5.1.4 Material Loss

This KPI measures the loss, misplacement, or untraceability of materials on a construction site by utilizing RFID technology to tag and track each item for real-time monitoring in predetermined areas. Building Information Modeling (BIM) predetermines specific storage and usage zones for materials, and when materials are not located in their expected zones or are completely missing, the system identifies them as misplaced or lost. By relating the overall items received to those lost or misplaced within a given timeframe, this KPI provides a measure of site supervision efficiency and inventory control. As construction sites are susceptible to loss of materials, theft, and inadequate tracking, this can lead to severe delays in workflows. Therefore, this approach would enhance accountability and refine materials security protocols in combination with the defined zones in BIM.

Formula:

$$\text{Material Loss (\%)} = \left(\frac{\text{Number of lost materials}}{\text{Total number of materials received}}\right) \times 100 \tag{5.4}$$

Where:

- Number of lost materials = Items that are either not found in their BIM-defined zones or are missing entirely based on RFID scan data.
- Total number of materials received = The number of materials scanned and registered upon arrival on-site (also tracked via RFID).

Interpretation:

- 0% = Ideal scenario; all materials are properly tracked and stored.
- Higher values = Indicate issues with inventory control, site supervision, or security.

Frequency: Monthly

Data source:

- RFID tracking system (read rates, last known locations)
- BIM model (material allocation and tracking zones)
- Inventory control systems

Data requirement:

- List of expected vs. actual material locations
- Records of unscanned RFID tags over time
- Allocation zones and expected installation times from BIM

Information requirement:

- Detection of theft, misplacement, or hoarding of materials
- Insight into field logistics and supervision effectiveness
- Ability to trace material flow for accountability

5.1.5 Material Handling Efficiency

This KPI is used to monitor the efficiency of material transportation between installation sites and delivery points within a BIM environment, where material paths and handling durations are pre-planned. With the application of RFID technology, alongside indoor positioning or scanning zones, real-time tracking of RFID-tagged materials allows comparisons to be made between actual time or distance traveled and the planned amount from the BIM model. This examination will help identify inefficiencies in the material logistics, such as detours, delays in handling, or inefficiencies in coordination. These inefficiencies are necessary to know since excessive handling time will lead to project delay, labor inefficiency, and even material damage, ultimately benefiting the project managers by enabling them to improve site layout and delivery approaches.

Formula:

$$\text{Material Handling Efficiency (\%)} = \left(\frac{\text{Planned handling time or distance}}{\text{Actual handling time or distance}}\right) \times 100 \tag{5.5}$$

Where:

- Planned handling time/distance = The expected duration or path of material movement based on BIM logistics planning.
- Actual handling time/distance = The real-time duration or distance tracked via RFID scans and positioning systems (e.g., from delivery point to installation zone).

Interpretation:

- 100% or above = Efficient handling; materials are moved as planned or faster.
- Below 100% = Inefficiencies exist; delays or longer-than-planned routes were used.

Frequency: Bi-weekly or per material delivery cycle

Data source:

- RFID reader logs (location and timestamps)
- BIM logistics/planning model (planned paths, zones, and locations)

- Indoor positioning systems (IPS), GPS (for outdoor)

Data requirement:

- RFID scan timestamps at delivery and installation points
- Planned movement paths or handling times from BIM
- Material IDs linked to delivery and installation activities

Information requirement:

- Deviations in time or movement patterns from BIM-defined logistics
- Identification of material bottlenecks or misplacements
- Trends in handling inefficiencies by crew, material type, or location

5.2 Literature Review of Construction 4.0 Technology

5.2.1 Building Information Modeling in Supply Chain

The first construction 4.0 technology that can be effectively incorporated into the project is Building Information Modeling. BIM is identified as a methodology with a strong potential for enhancing the performance of construction supply chains [10], as exemplified in Figure 5.1. As a digital backbone and a technological enabler, BIM facilitates up-to-date information exchange and collaboration among actors. BIM deployment in the reinforcement supply chain, for example, can considerably enhance project performance by providing richer and more accurate information [11]. BIM can connect information related to building design, procurement, and construction, promoting coordination, cooperation, information sharing, and integration among various project participants in the supply chain [12].

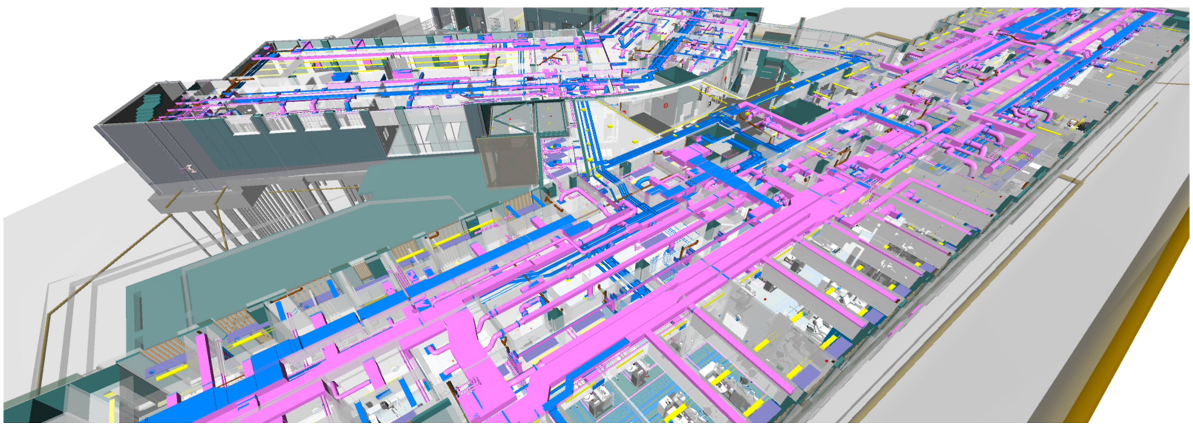

Figure 5.1: Material classification for supply chain in BIM authoring tool [1]

BIM-enabled supply chain management can lead to significant improvements and support collaborative planning and management of the supply chain for the selected case project. It would also contribute to lean construction and eliminate waste by enabling transparent processes, signaling bottlenecks, and allowing stable workflow, contrasting with traditional practices of shifting risks to other supply chain parties [10]. In the case project, BIM would allow contractors and suppliers to access information as it is created by any party, enable real-time control of material flows and interdependent activities, such as logistics management and quality control [10]. BIM's potential for enhancing efficiency spans various aspects of the construction supply chain, which can be implemented in the case project:

- **Procurement of building materials/components**: BIM can help the process by taking material quantities and cost estimates and keeping interested parties aware of changes in design. With its full and accurate information, BIM facilitates more precise procurement. In addition, BIM's central storage of data and accessibility to all supply chain stakeholders can decrease information waiting times and lower on-site inventory levels [10].

- **Off-site production of building materials/components**: Real-time information exchange regarding fabrication scheduling is necessary to prevent delays and reworks on site, especially during design changes [10].
- **Transportation & Logistics**: Effective logistics management is compulsory in supply chain operations, as poor management would lead to excessive waste. When materials are not available when required, it can lead to delays. BIM can assist in decision-making by ensuring that materials are supplied on time and in the correct quantities and quality. Besides, BIM-based systems can generate forecasts and alerts regarding inventory level, which enables early orders for replenishment [10].
- **On-site Assembly/Construction**: Just-in-time (JIT) delivery, facilitated by BIM integration, transfers inventory costs and risks to the supplier [11]. BIM can assist in ensuring materials flow from the digital environment (model) to the real world (site) and back, creating a ”digital twin” for added value to the client [11]. BIM also helps to resolve issues with disconnected information transfer during various processes and a lack of cooperation across different specialties, which is key to effectively avoiding disruptions and improving resilience [12].

Furthermore, integrating BIM with other technologies can even further enhance efficiency. The potential use of RFID sensors for tracking materials in a fully materials in a fully connected supply chain is envisioned.

5.2.2 Radio Frequency Identification in Supply Chain

Moreover, the second construction 4.0 technology that has a substantial effect on the selected construction scenario is Radio Frequency Identification (RFID). RFID, considered a critical pillar of the Internet of Things (IoT), emerges as a promising solution for improving connectivity and real-time information delivery in construction projects.

RFID technology is an automated data collection and identification technology consisting of tags, readers, and middleware [13]. Using radio waves, it can identify, record, and track objects wirelessly, often without the need for physical contact or a clean environment [14] [13]. RFID-based systems can quickly assemble data from many tags, reduce manual counting operations, prevent errors, continuously check inventory, and monitor and locate items throughout a construction site [14]. In the case project, this capability would enable risk-free logistics and reliable transport, which can reduce management investment and increase service quality. RFID would also be optimal for the construction operation for implementation as it would help save cost as it has low installation costs, easy implementation, and high interoperability [14].

The system would help maintain workflow and avoid stoppages and non-value-adding activities, which contribute to overall project efficiency [14]. Furthermore, it would also improve the ordering system along the supply chain. Managers using the platform would be able to receive and share real-time information about material status, monitor and improve orders to ensure materials are delivered at the right time and in the right quantities, and receive alerts for low material levels [14].

Additionally, in warehouses, RFID would make the job easier for staff and managers, helping users pick orders from the correct shelves within an optimal time, reducing effort and search time, and managers would only monitor operations remotely [13], like the system integration depicted in Figure 5.2. RFID would improve inventory management by enabling precise data collection from the supplier stage through storage and distribution [15]. This real-time data can reduce waste and improve quality, predict demand fluctuations, and optimize logistics by coordinating demand with supply, identifying bottlenecks, and suggesting alternatives.

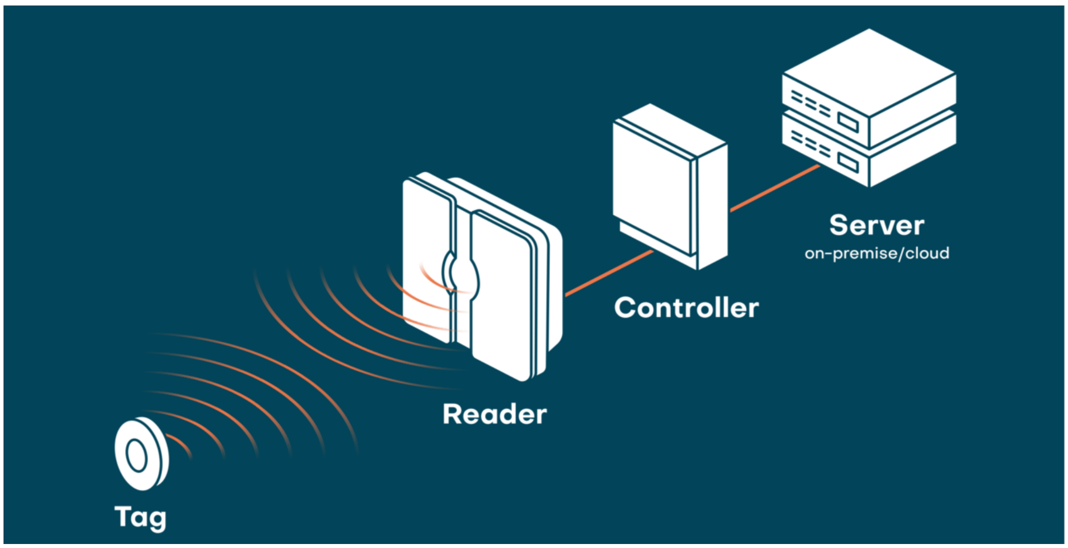

Figure 5.2: Integrated RFID tracking system [2]

The RFID-based warehouse system would help decrease human errors through automation, integrating activities for process continuity, and using data analysis for estimating material quantity needs, in which the errors reduced by RFID can significantly increase total revenue [15].

5.3 Justification of Construction 4.0 Technology

To address the stated problem using the designed KPI's defined in Section 5.1, according to the conducted literature review in Sections 5.2.1 and 5.2.2, integrating Building Information Modeling (BIM) and Radio Frequency Identification (RFID) holds strong potential for enhancing the performance of construction supply chains. BIM serves as a digital backbone and a technological enabler for up-to-date information exchange and collaboration, providing detailed digital models and data about project components and requirements. RFID, as a key pillar of the Internet of Things (IoT), offers a promising solution for real-time information delivery and tracking of materials in the physical world. By integrating two technologies, such as linking RFID tag data to the BIM model, a digital bridge is created between physical building elements and their digital counterparts. This allows for real-time tracking and identification of materials and components throughout the supply chain stages, from fabrication to installation on site. This integration enables improved visibility and traceability, facilitates enhanced information sharing and communication among supply chain members, and supports automated data collection and synchronization. The combined use of BIM and RFID aids in streamlined logistics, better coordination of interdependent activities, and improved operational efficiency by reducing manual tracking and errors. Ultimately, this technological integration supports decision-making, helps reduce cost and waste through optimized deliveries and inventory management, and can increase the overall performance of the construction supply chain and project workflow.

Data Schema of the System

In the previous section, we conducted a literature study that led us to a proposed solution of a system that integrates Building Information Modeling (BIM) and Radio-Frequency Identification (RFID). By using these two technologies together, we aim to improve real-time data management and the overall workflow of a construction project.

The BPMN, located in Appendix A, is thoughtfully organized into five distinct swim lanes, each symbolizing a unique stage of the process. This structure seamlessly incorporates the two proposed technologies—sensors, databases, data processing, suppliers, and the front-end. The BPMN depicts the dynamic interaction between the physical components, including RFID sensors, and the digital platforms, such as BIM software and cloud databases.

In the first stage, the process starts with the collection of raw data from the RFID tags embedded in the materials. In the RFID tags, we can find information that allows us to track the materials, such as quantity or location. This data provides a real-time inventory of the available material on our construction site.

Subsequently, databases are employed to store real-time updated information. The input on the current inventory of the material is stored in a cloud database. At the same time, updated data about the schedule affected by the presence of the materials is stored alongside the information obtained from the BIM models in a joint database called Project Intended Information (PII). At this stage, at least BIM Level 350 (As Built) is needed to realize real-time material tracking.

After storing the data, it is processed and analyzed. A comparison between the updated inventory materials and the projected material needs is made, given as a result the Real Material Needs (RMN).

The Real Material Needs data is sent to both the supplier and a dashboard located at the construction site. At this phase, we will focus on the interaction with the first ones: once the supplier has received this information, an internal verification of its inventory is realized, obtaining the Material Capacity of the Supplier (MCS). A comparison between these two is realized if the Material Capacity of the Supplier is lower than the Real Material Needs; automatically, Supplier Number Two is contacted, and the loop is performed again. The loop stops when MCS is equal to or greater than RMN. The reliability of the suppliers regarding their capacity (stock) to provide the materials demanded and to provide them on time could be measured with data obtained at this stage of the process.

Finally, the order is confirmed, and the supplier delivers the materials to the construction site. With the intention of sharing data, the dashboard displays information regarding the materials that will be delivered: this could include materials quantity or expected date of delivery and date of arrival on site that will help us to track the adherence to the schedule in the project. The new materials that arrive will also have embedded RFID tags with information that will enter the system, restarting the system.

Without this system, the order and delivery of materials are often improvised. Our goal is to try to minimize improvisation regarding ad-hoc material provisioning and improve the schedule adherence. This will build trust among stakeholders while reducing costs, materials waste and inefficient labor allocation.

Barriers and Mitigation Strategies of Construction 4.0 Technology

In this chapter, the challenges associated with BIM and RFID adoption and implementation are reviewed. It provides a glimpse into mitigation strategies that can be implemented to prevent these challenges. However, it has to be realized that the suggested strategies may not altogether avoid the challenges that will be encountered, and research into deeper solutions will be necessary.

7.1 Barriers and Mitigation Strategies of BIM Implementation

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The delay in the implementation of BIM, especially in small companies, is the high cost associated with it [16]. This can include software licenses and the specialized training needed to tackle the lack of professionals with proficient skills in the use of BIM tools, particularly interdisciplinary communication and collaboration competencies [17]. It is recommended that governments support small and medium-sized enterprises with financial aid to help them launch BIM in construction projects [18].

However, purely technical, root-cause reasons that object to the implementation of BIM are rare compared to social barriers. There is a resistance to change [19] with a lack of management that supports its use: traditional workflows and the lack of cooperation and experience or data sharing among different stakeholders, usually happening in the construction industry, could be one of the reasons. In this case, the mandatory use of BIM in state public-funded projects could be a way to promote its implementation.

Another concern is data security. A construction project consists of several stages where information passes through multiple participants, resulting in the need to consider security in the BIM information life-cycle [20]. To address this issue, the implementation of blockchain is proposed, as it integrates several technologies (peer-to-peer networking, asymmetric encryption, and consensus algorithms) that support the collaborative environment of BIM.

7.2 Barriers and Mitigation Strategies of RFID Implementation

A big issue to address regarding RFID is also privacy due to a weak unilateral authentication and identification [21] and the attached risk of privacy leakage. In construction, and particularly in our proposal, there is a need to share information about the materials that will be used in a part of the construction project. The data obtained from RFID tags could be shared with competitors or used for other purposes. This is why the implementation of security protocols is suggested to be complemented with blockchain technology [22] with a hybrid access control mechanism to safeguard unauthorized access to confidential data within the construction framework. This has proved to enhance security while building trust [23].

Besides the wide range of applications of RFID, another limitation is regarding the interferences [24] produced by certain materials like metals and concrete, which unfortunately is very common in construction projects. These problems can be overcome if other technologies are combined with RFID, including vision and positioning systems, microcomputers, and software integration [25]. The combination with other technologies, similarly to what we propose with this project, offers an increased range of solutions to problems we face in the construction field.

Conclusion

This report conducted a holistic study of a construction project, beginning with an in-depth analysis of its context and challenges. Through systematic problem definition and scenario selection, the report concluded primary inefficiencies and areas for improvement in the construction supply chain for the case project. The resolution design employed key performance indicators and explored the extensive potential of Construction 4.0 technologies, namely BIM and RFID. The proposed data schema and implementation strategies offer a practical roadmap for integrating these technologies, while the discussion on barriers and mitigation strategies ensures a realistic approach to adoption. This report underscores the importance of digital transformation in Construction 4.0 for modern construction practices. The findings and recommendations presented aim to support stakeholders in achieving greater reliability, transparency, and sustainability in construction supply chain management.

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Appendices

Appendix A: Business Process Model and Notation of the System