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Identification of the CSFs for the Implementation of BIM in Construction Project Management for the Digitalisation of Manual Processes

Supervisors:
Alberto De Marco
Filippo Maria Ottaviani

Candidate:
Lorenzo Gavinelli

Abstract

This thesis investigates the critical success factors (CSFs) for the successful implementation of Building Information Modelling (BIM) in construction project management, with a focus on the digital transformation of traditional manual processes. BIM is a powerful tool that integrates multiple aspects of construction management, improving efficiency, collaboration and decision-making throughout the project lifecycle. Through an extensive literature review and the application of the Analytical Hierarchy Process (AHP), this research identifies and prioritises key criteria that influence the success of BIM adoption, including process improvement, strategic alignment, technology integration, organisational change management, regulatory compliance, and user training and support.

The study highlights the significant benefits of BIM, such as improved workflow efficiency, reduced project duration, improved data accuracy and better alignment with organisational goals. In addition, the research shows that BIM contributes to long-term value creation and competitive advantage when integrated with an organisation's strategic objectives. However, limitations such as geographical scope and reliance on expert judgement in the AHP process are acknowledged and provide opportunities for future research.

This thesis provides a practical framework for decision makers in the construction industry, offering insights into how BIM can be effectively implemented to facilitate digital transformation. Recommendations for future research include exploring ways to overcome barriers to widespread BIM adoption and integrating emerging technologies such as artificial intelligence (AI) and the Internet of Things (IoT). The findings highlight the strategic importance of BIM as a driver of innovation, efficiency and improved project management in the construction industry.

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1. Introduction to BIM and Digitalization in Construction

1.1 Overview of Building Information Modelling (BIM)

Building Information Modelling (BIM) represents a significant technological advance in the construction industry, providing a comprehensive approach to project management and delivery. BIM is defined as "a digital representation of the physical and functional characteristics of a building" that serves as a common knowledge resource for information about a building, providing a reliable basis for decision making throughout its lifecycle from inception (National Institute of Building Sciences, 2007). This definition emphasises BIM's role as a central repository of information that integrates various aspects of a building project, from initial design through construction, operation and even demolition or refurbishment.

The impact of BIM on the construction industry cannot be overestimated. It has transformed traditional practices by enabling more collaborative, efficient and sustainable project delivery. The integration of BIM into construction processes allows for better visualisation, simulation, and optimisation of projects, leading to improved outcomes in terms of cost, time, and quality (Eastman et al., 2011). Furthermore, BIM facilitates the involvement of multiple stakeholders in the decision-making process, ensuring that all relevant data is considered and that the project evolves with a holistic understanding of its lifecycle (Kassem et al., 2015).

The concept of BIM has evolved significantly over the last few decades. Its roots can be traced back to the 1960s, with the advent of computer-aided design (CAD) technologies. CAD revolutionised the way architects and engineers produced drawings, moving from manual drafting to digital design. However, early CAD systems were limited to two-dimensional (2D) representations, which, while an improvement over manual methods, lacked the depth and integration required to manage complex construction projects (Eastman et al., 2011).

The term 'BIM' began to gain prominence in the early 2000s, accelerated by Autodesk's 2002 white paper, which outlined the potential of BIM as a comprehensive digital model that went beyond 2D and 3D representations to include additional dimensions such as time and cost (Autodesk, 2002). This was a significant milestone that brought the concept of BIM to the forefront of the construction industry and highlighted its potential to revolutionise project management and delivery.

Initially, BIM was primarily used for three-dimensional (3D) modelling, allowing designers and architects to create more accurate and detailed representations of buildings. However, as the technology developed, BIM expanded to include additional dimensions, enabling a more integrated and dynamic approach to construction project management. The introduction of 4D BIM, which integrates time-related information with 3D models, allows project managers to visualise construction sequences and schedules, optimising the planning process and reducing delays (Ghaffarianhoseini et al., 2017).

Further advances have led to the development of 5D BIM, which incorporates cost-related data into the model. This allows for more accurate budgeting and financial management throughout the project lifecycle, providing stakeholders with a clear understanding of how design changes will affect the overall project cost (Monteiro & Martins, 2013). The inclusion of cost data also facilitates better decision making by allowing project teams to compare different design options based on their financial implications.

In recent years, BIM has continued to evolve with the introduction of 6D BIM, which focuses on sustainability and energy efficiency. 6D BIM integrates environmental impact data such as energy consumption, material sustainability and carbon footprint into the model. This allows project teams to assess the sustainability of different design options and make informed decisions in line with environmental goals and regulations. The use of 6D BIM is particularly relevant in today's construction industry, where there is increasing pressure to deliver sustainable and energy efficient buildings.

More recently, the evolution of BIM has expanded to include 7D, which incorporates facilities management into the BIM model. 7D BIM enables the integration of operational data, helping facilities managers to optimise the maintenance and operation of buildings throughout their lifecycle. This dimension of BIM ensures that data created during the design and construction phase can be used throughout the building's life, reducing operational costs and improving building performance.
As BIM continues to evolve, it is increasingly integrated with other emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), and augmented reality

(AR). These technologies enhance the capabilities of BIM by providing real-time data, predictive analytics, and immersive experiences that improve project outcomes (Alizadehsalehi et al., 2020). For example, the integration of IoT with BIM enables continuous monitoring of building performance, enabling proactive maintenance and optimisation of energy use. AI enhances BIM by providing advanced analytics and machine learning algorithms that can predict project risks and optimise construction processes (Zhou et al., 2019). Meanwhile, AR applications in BIM provide immersive visualisation tools that help stakeholders better understand complex designs and construction processes.

The evolution of BIM from a simple digital drawing tool to a comprehensive project management platform reflects the broader trend of digital transformation in the construction industry. As BIM continues to integrate with other digital technologies, it is likely to play an even more central role in shaping the future of construction, driving innovation and improving project outcomes.

1.1.1 Key Features of BIM

Building Information Modelling (BIM) is a transformative technology in the construction industry, integrating multiple dimensions of a project into a single, coherent model that improves efficiency, collaboration and decision-making. The key features of BIM are central to its adoption and impact across the industry:

- **3D Modeling**:
  At the heart of BIM is the ability to create detailed, three-dimensional (3D) digital models of buildings. These models provide a comprehensive visual representation of a project, enabling stakeholders to better understand the design intent and anticipate potential issues before they arise during construction. This capability is invaluable for design visualisation, allowing architects and clients to see the final product in a realistic form before any physical work begins. BIM's 3D modelling capabilities also support advanced analyses, such as structural integrity assessments and energy performance simulations, which contribute to more sustainable and efficient building designs (Wang & Chong, 2015).
- **Data Integration**:
  One of the most powerful features of BIM is its ability to integrate data from multiple sources, creating a centralised information hub for a construction project.

This integration extends beyond the geometric data of 3D models to include specifications, schedules, costs and materials, ensuring that all stakeholders have access to accurate and up-to-date information (Eastman et al., 2011). More recent studies have highlighted the role of BIM in facilitating data-driven decision making, with real-time data integration enabling project managers to track progress, manage resources, and optimise workflows (Abdirad & Dossick, 2016). The ability to maintain a single source of truth through BIM reduces the risk of errors and miscommunication that are common in traditional construction processes, where information is fragmented across different platforms.

- **Collaboration and Communication**:
  One of the key benefits of BIM is its ability to improve collaboration and communication between project stakeholders. Traditionally, architects, engineers, contractors and other stakeholders have worked in silos, leading to inefficiencies and misunderstandings. BIM overcomes this by providing a common platform where all participants can collaborate, share information and coordinate their activities in real time (Gu & London, 2010). This collaborative environment is particularly beneficial in complex projects where coordination between different disciplines is critical. Recent research has shown that BIM facilitates a more integrated project delivery approach where all stakeholders work together from the earliest stages of the project, leading to improved outcomes in terms of cost, time and quality (Charef et al., 2018).
- **Lifecycle Management**:
  Beyond the design and construction phase, BIM supports the entire lifecycle of a building, from conception to demolition or refurbishment. This lifecycle approach ensures that all stages of the building's life are considered and planned for from the outset, leading to more sustainable and cost-effective. BIM enables facility managers to use the data-rich model created during design and construction to manage operations and maintenance more effectively, a process often referred to as building lifecycle management (BLM).
- **4D and 5D Modeling**:
  In addition to traditional 3D modelling, BIM also includes 4D (time) and 5D (cost) modelling, which integrate project scheduling and cost estimation into the BIM process. 4D BIM allows project managers to visualise the construction sequence over time, helping to identify potential scheduling conflicts and optimise

the construction schedule. 5D BIM, on the other hand, links the model to cost estimates, enabling more accurate budgeting and financial management throughout the project lifecycle. These additional dimensions of BIM provide a more comprehensive view of the project, helping to ensure that it is delivered on time and within budget (Monteiro & Martins, 2013).

- **Sustainability and Energy Efficiency**:
  Sustainability is a growing concern in the construction industry, and BIM plays a critical role in promoting energy efficient and environmentally friendly construction practices. BIM enables the integration of energy analysis tools that can assess the environmental impact of different design options, helping architects and engineers to optimise buildings for energy efficiency . By simulating different design scenarios, BIM can identify the most sustainable options early in the design process, leading to buildings that are not only more efficient, but also comply with increasingly stringent environmental regulations (Berardi, 2019).
- **Virtual Reality (VR) and Augmented Reality (AR)**:
  The integration of virtual reality (VR) and augmented reality (AR) with BIM is an emerging trend that enhances visualisation and interaction with BIM models. VR allows stakeholders to immerse themselves in the BIM model, providing a more intuitive understanding of space and design, while AR overlays BIM data onto the physical environment, assisting with tasks such as site inspection and construction planning (Davila Delgado et al., 2020). These technologies not only improve the design review process, but also enhance training and safety on construction sites by providing more interactive and immersive experiences.

One of the most notable tools in the BIM ecosystem is Autodesk's BIM 360, a cloud-based platform designed to support BIM processes throughout the construction lifecycle. BIM 360 extends the capabilities of traditional BIM by enabling real-time collaboration and data sharing across project teams, regardless of location

1.1.2 Key Features of BIM 360

BIM 360 is a comprehensive, cloud-based platform that offers a suite of integrated modules designed to enhance various aspects of construction management. By addressing the entire project lifecycle, from design through construction and operations, BIM 360 provides a centralised environment where all stakeholders can collaborate effectively, access critical project data and manage tasks in real time. Below are the key modules of BIM 360, each addressing specific needs within the construction process:

- **BIM 360 Docs**:
  BIM 360 Docs is the foundation of the BIM 360 suite and acts as a centralised document management system, ensuring that all project documentation is securely stored and readily accessible to authorised team members. This module is critical for maintaining a single source of truth for all project-related data, which is essential for reducing the risk of errors associated with outdated or incorrect information. BIM 360 Docs supports a wide range of document types, including drawings, models and specifications, and provides version control to ensure that team members are always working with the latest documents. It also allows users to set permissions and manage access to sensitive information, ensuring that data security is maintained throughout the project lifecycle. By providing real-time access to project documentation, BIM 360 Docs facilitates better decision-making and streamlines communication between teams, significantly improving project efficiency.
- **BIM 360 Design**:
  BIM 360 Design extends the capabilities of BIM 360 Docs by focusing specifically on the collaborative design process. This module enables multiple stakeholders, including architects, engineers and designers, to work on the same Revit model at the same time, regardless of their physical location. This collaborative environment is particularly beneficial for complex projects where coordination between different disciplines is critical to success. BIM 360 Design supports real-time co-authoring, where changes made by one team member are immediately visible to others, reducing the risk of conflict and ensuring that the design remains consistent throughout. The module also includes features such as design review workflows, issue tracking and change visualisation, which help teams manage and resolve design issues efficiently. By facilitating better collaboration and coordination, BIM 360 Design not only accelerates the design phase, but also improves the overall quality of the final product.
- **BIM 360 Coordinate**:
  BIM 360 Coordinate is a powerful tool designed to improve project coordination

through advanced clash detection and resolution capabilities. Clash detection is a critical aspect of construction management, as it involves identifying and resolving potential conflicts between different building systems, such as electrical, plumbing and HVAC, before they are physically constructed. BIM 360 Coordinate allows project teams to perform automated clash detection tests on their BIM models, identifying issues early in the design process when they are easier and less costly to resolve. The module provides a visual representation of clashes, allowing teams to quickly understand the nature and location of conflicts. It also supports collaboration by allowing team members to assign, track and manage the resolution of clashes, ensuring that all issues are addressed before construction begins. This proactive approach to coordination reduces the likelihood of costly field conflicts and rework, ultimately contributing to smoother project delivery and more predictable outcomes.

- **BIM 360 Build**:
  BIM 360 Build focuses on the field management aspect of construction, providing tools that enable project teams to track quality, safety and project controls directly from the site. This module is particularly valuable for site managers, inspectors and contractors who need to effectively manage site activities. BIM 360 Build includes functionality for issue management, allowing teams to document, assign, and resolve issues as they arise, ensuring that issues are addressed quickly and do not impact the overall project schedule. The module also supports progress tracking, allowing site teams to update the status of various tasks in real time, providing project managers with up-to-date information on project performance. In addition, BIM 360 Build offers robust reporting tools that provide insight into project health, helping teams monitor key performance indicators (KPIs) such as safety compliance, quality standards, and schedule adherence. By integrating these capabilities, BIM 360 Build ensures that construction projects are delivered on time, on budget and to the highest standards of quality and safety.
- **BIM 360 Field:**

  BIM 360 Field is a powerful mobile tool that significantly enhances the capabilities of the BIM 360 suite by extending its functionality directly to the job site. This application allows field workers, including site managers, inspectors and subcontractors, to access and update critical project information in real time, no matter where they are. This seamless access to data ensures that all team members are working with the most up-to-date and accurate information, which is essential to maintaining project accuracy and efficiency.

One of the key features of BIM 360 Field is its support for punch lists, a critical aspect of construction management. Punch lists are used to identify and track items that need to be completed, corrected or checked before the project can be considered complete. With BIM 360 Field, punch lists can be created, updated and managed in the field using a mobile device, eliminating the need for manual paperwork and reducing the risk of errors or omissions. This functionality helps to ensure that issues are addressed promptly, contributing to higher project quality and timely completion.

Equipment tracking is another key feature of BIM 360 Field. In the dynamic environment of a construction site, keeping track of equipment can be challenging. BIM 360 Field allows users to document and monitor the location, condition and use of equipment directly from their mobile devices. This capability not only helps prevent the loss or misuse of expensive tools and machinery, but also ensures that the right equipment is available when and where it's needed, avoiding costly delays.

Quality inspections are also streamlined with BIM 360 Field. The tool enables field workers to perform inspections, record observations and take corrective action without leaving the job site. This real-time data capture improves the accuracy and timeliness of inspections, ensuring that quality issues are quickly identified and resolved. The ability to attach photos, notes and other documentation directly to inspection reports improves communication between the field and the office, facilitating better decision-making and more efficient project management.

In addition, BIM 360 Field's integration with the wider BIM 360 ecosystem ensures that all data collected in the field is automatically synchronised with the central project database. This seamless flow of data between the field and the office is critical to maintaining up-to-date project records, enabling all stakeholders to access the latest information and coordinate their efforts effectively. By bridging the gap between the field and the office, BIM 360 Field plays a critical role in improving the overall efficiency, accuracy and quality of construction projects.

1.1.3 Benefits of BIM in Construction

The integration of Building Information Modelling (BIM) and advanced platforms such as BIM 360 has fundamentally changed the construction industry, offering significant improvements in various facets of project management and delivery. One of the most prominent benefits is the dramatic increase in efficiency and productivity. BIM facilitates the creation of highly accurate and detailed 3D models, drastically reducing the likelihood of errors and the need for costly rework - a common problem in traditional construction methods. This reduction in errors and rework not only shortens project timelines by up to 30%, but also leads to significant cost savings, often in excess of 20% (Bryde et al., 2013). The BIM 360 platform further enhances these efficiencies by enabling real-time collaboration between all project stakeholders, ensuring that everyone, whether on-site or remote, is working with the most up-to-date information. This capability is particularly important for complex projects involving multiple disciplines, where seamless coordination and communication are essential to prevent delays and misunderstandings (Hardin & McCool, 2015).

In addition to improving efficiency, BIM significantly improves decision-making throughout the project lifecycle. The data-rich environment provided by BIM includes not only the geometry of the building, but also detailed information on materials, costs, schedules and environmental impact. This comprehensive dataset enables project managers and other stakeholders to make informed decisions at every stage, from initial design through to construction and operation. The ability to access real-time data through platforms such as BIM 360 is particularly valuable in fast-paced construction environments, where delays in decision making can lead to significant cost overruns and schedule disruptions (Eastman et al., 2011; Volk et al., 2014). The platform's ability to provide instant access to critical information, regardless of a decision-maker's location, ensures that projects stay on track and on budget.

Another critical area where BIM adds value is in risk mitigation. BIM's ability to simulate different construction scenarios - such as sequencing, material logistics and environmental conditions - enables project teams to identify and address potential issues before they manifest themselves on site. This proactive approach minimises the risk of costly on-site conflicts and ensures smoother project delivery (Love et al., 2013). BIM 360 tools such as clash detection and issue management are particularly effective in identifying and resolving clashes between different building systems (e.g. structural, electrical, plumbing) during the design phase, thereby preventing these issues from escalating into major problems during construction. Furthermore, the ability to document and track issues in real time through BIM 360 not only maintains project quality and safety standards, but also further mitigates risk by ensuring that issues are addressed promptly and effectively.

Finally, BIM is increasingly recognised as an important tool for promoting sustainability in the construction industry. By enabling detailed analysis of a building's environmental impact - such as energy consumption, material use and waste generation - BIM helps designers and engineers optimise buildings for sustainability from the outset (Chong et al., 2017). This capability is particularly important given the growing emphasis on sustainable construction practices and the need to comply with stringent environmental regulations. BIM allows project teams to evaluate different design options based on their sustainability performance, enabling them to select the most environmentally friendly solutions. In addition, BIM 360 enhances sustainability efforts by providing tools to more effectively track and manage resources throughout the construction process. For example, BIM 360 can be used to monitor on-site material usage and waste, helping teams to minimise waste and reduce the overall environmental footprint of the project (Davila Delgado et al., 2020).

In summary, the adoption of BIM and platforms such as BIM 360 has led to a paradigm shift in the construction industry, driving improvements in efficiency, decision-making, risk management and sustainability. These tools not only streamline construction processes, but also contribute to more sustainable and cost-effective project outcomes, making them indispensable in modern construction practices.

1.2 Digitalization in Construction

1.2.1 The Broader Trend of Digitalization

Digitalisation in the construction industry refers to the use of digital technologies to transform traditional construction processes. This transformation is not isolated, but part of a broader trend across industries, driven by rapid advances in information technology. These advances have led to significant improvements in efficiency, cost reduction and overall quality of products and services across various sectors.

Traditionally known for its reliance on manual labour and paper-based processes, the construction industry is undergoing a digital revolution, with technologies such as Building Information Modelling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT) and advanced data analytics increasingly being integrated into everyday practice (Gerbert et al., 2016). This digital transformation is not just about replacing paper with digital tools, but about fundamentally changing the way construction projects are conceived, designed, managed, and executed. The integration of these technologies enables a more connected, efficient, and sustainable construction process that fosters a culture of innovation and continuous improvement.

1.2.2 Shift from Manual to Digital Processes

Traditionally, the construction process relied heavily on manual tasks, including extensive paperwork, manual drawings, and on-the-spot decision making. While these methods were effective for their time, they often led to inefficiencies, delays, and increased costs due to miscommunication, errors, and slow dissemination of information (Miettinen & Paavola, 2014). Over the past two decades, however, the industry has witnessed a significant shift towards digital processes. The adoption of digital tools such as BIM, advanced project management software and mobile applications has revolutionised the way construction projects are designed, managed and executed (Love et al., 2013). These tools facilitate real-time collaboration, allowing teams to work together seamlessly regardless of their physical location, which is particularly beneficial in the increasingly globalised construction industry. Digital tools also improve data accuracy, reduce the likelihood of errors, and enable more effective project tracking and control, leading to better project outcomes (Volk et al., 2014).

For example, the transition from 2D paper-based drawings to 3D digital models has transformed the way architects and engineers approach design and construction. These 3D models not only provide a more accurate representation of the building, but also allow for the integration of additional dimensions such as time (4D) and cost (5D), further enhancing the ability to plan and manage construction projects (Wang & Chong, 2015). In addition, the use of mobile applications on construction sites has streamlined communication between the office and the field, enabling real-time updates and instant access to project data, significantly reducing delays and improving decision making.

1.2.3 BIM's Role in the Digital Transformation

BIM is at the heart of digital transformation in the construction industry. As a comprehensive tool that integrates all aspects of construction management, BIM acts as the foundation for digital processes in the industry. It supports the transition away from manual methods by providing a digital platform where all project data is stored, managed and shared between stakeholders (Eastman et al., 2011). Unlike traditional methods, where information is often siloed between different teams, BIM enables a more collaborative approach by integrating data from different disciplines into a single, coherent model. This integration facilitates better coordination, reduces the risk of errors and ensures that all parties are working from the same up-to-date information (Gu & London, 2010).

BIM enhances traditional construction methods by offering new capabilities such as clash detection, virtual construction and facility management. Clash detection, for example, allows project teams to identify and resolve conflicts between different building systems (e.g. structural, mechanical, electrical) before construction begins, significantly reducing the likelihood of costly rework (Wang & Chong, 2015). Virtual construction supported by BIM enables the simulation of construction processes, allowing teams to more effectively plan and optimise construction sequences, material logistics and site layouts (Ghaffarianhoseini et al., 2017). Furthermore, BIM extends beyond the construction phase into facilities management, where it serves as a valuable tool for managing building operations, maintenance, and refurbishment throughout the building's lifecycle (Kassem et al., 2015). The integration of cloud-based platforms such as BIM 360 further extends these capabilities into the cloud, enabling more dynamic, responsive and real-time project management across geographically dispersed teams.

1.2.4 Case Studies and Applications

Numerous case studies highlight the impact of BIM and BIM 360 on the digitisation of construction processes. One notable example is the UK government's mandate for BIM Level 2 on all public sector projects by 2016, which significantly accelerated the adoption of digital technologies in the construction industry (Eadie et al., 2013). This mandate not only promoted the use of BIM on public projects, but also acted as a catalyst for wider industry adoption, encouraging private sector companies to integrate BIM into their practices. The results have been profound, with significant improvements in project delivery times, cost savings and overall project quality reported across various projects.

Another example is the construction of the Hong Kong International Airport, where BIM and BIM 360 were used to manage complex logistics and scheduling. This project demonstrated the ability of BIM to handle large-scale infrastructure projects by providing a centralised platform to manage the myriad of components and stakeholders involved. The use of BIM enabled the project team to coordinate effectively, track progress in real time, and ensure that the project stayed on schedule and within budget. These case studies illustrate the transformative impact of BIM and BIM 360 on large and complex projects, highlighting their potential to streamline construction processes, enhance collaboration, and deliver better outcomes.

1.2.5 Challenges in Digital Transformation

Despite the many benefits, the digitisation of construction through BIM and tools such as BIM 360 presents several challenges. One of the main challenges is the high cost of implementation. The initial investment in BIM software, hardware and training can be significant, especially for small to medium-sized enterprises (SMEs) (Miettinen & Paavola, 2014). These costs are not only financial, but also include the time required to train staff and integrate BIM into existing workflows. In addition, the transition to digital processes requires a cultural change within organisations, as employees may be reluctant to adopt new technologies and change established practices.

Another significant challenge is the need for extensive training and education. BIM is a sophisticated tool that requires specialised knowledge to use effectively. The shortage of skilled professionals who are familiar with BIM is a barrier to its widespread adoption, as companies may struggle to find or train staff with the necessary expertise (Love et al., 2013). Furthermore, the integration of BIM with other digital tools, such as project management software, IoT and AI, requires standardisation and interoperability, which are still evolving within the industry (Oesterreich & Teuteberg, 2016). Without standardised data formats and protocols, it can be difficult to seamlessly exchange information between different tools and platforms, leading to inefficiencies and potential data loss.

2. The Role of BIM in Construction Project Management

2.1 BIM's Impact on Project Management

Building Information Modelling (BIM) has revolutionised construction project management by providing tools and processes that integrate all aspects of a project's lifecycle, from initial design to construction and facility management. BIM's impact on project management can be observed in several critical areas:

2.1.1 Planning and Design

BIM significantly improves the planning and design phases of construction projects. Traditional methods relied on two-dimensional drawings, which often led to misunderstandings and discrepancies when interpreting the design. BIM, on the other hand, provides a three-dimensional (3D) digital representation of the project, allowing for more accurate visualisation and analysis. This improved clarity helps project stakeholders to better understand the project scope, identify potential design conflicts early, and make informed decisions before construction begins.

In addition, the ability to incorporate time (4D) and cost (5D) data into the BIM model allows project managers to simulate construction schedules and budget estimates. This enables more effective planning and resource allocation, helping to avoid delays and cost overruns (Eastman et al, 2011). By integrating different data streams into a single model, BIM supports a holistic approach to project management, where all aspects are considered together.

2.1.2 Execution and Construction

During the execution phase, BIM continues to offer significant benefits. One of the key benefits is its ability to improve coordination between the different trades involved in construction. BIM models can be used to perform clash detection, identifying areas where different systems (such as electrical, plumbing and HVAC) may interfere with each other. This proactive identification of potential conflicts reduces the likelihood of costly and time-consuming rework once construction is underway (Gu & London, 2010).

In particular, BIM 360 enhances this aspect of project management by providing cloud-based coordination tools. BIM 360 Coordinate allows project teams to collaborate in real time, sharing models and clash detection results instantly with all stakeholders. This real-time collaboration ensures that everyone is working from the most current information, reducing the chances of errors and omissions.

2.1.3 Monitoring and Control

BIM also plays a critical role in the monitoring and control of construction projects. Traditional project management relies heavily on manual reporting and periodic updates, which can lead to delays in identifying and addressing problems. BIM, however, allows continuous monitoring of project progress through its integrated model, providing real-time data on various project metrics (Love et al., 2013).

BIM 360 Build, a module within the BIM 360 suite, is particularly valuable in this regard. It allows field workers to report progress, track quality and manage issues directly from the site using mobile devices. This direct input from the field into the BIM model ensures that project managers have up-to-date information at all times, allowing for more agile decision making and quicker response to any issues that arise.

2.1.4 Lifecycle Management

Beyond the construction phase, the impact of BIM extends to the lifecycle management of the building. The detailed digital model created during the design and construction phase serves as a valuable asset for facility managers, who can use it to plan maintenance activities, track the condition of building components, and manage renovations or retrofits. BIM 360 Ops further supports this by providing a mobile-first asset and maintenance management solution that connects building operations with the original BIM data, ensuring continuity and accuracy throughout the building.

2.2 Manual vs. Digital Processes

2.2.1 Comparison of Traditional Manual Processes and BIM-Enhanced Processes

In the traditional construction process, many tasks were performed manually, relying on paper-based documents, physical drawings and face-to-face meetings to coordinate work. This approach often led to inefficiencies such as delays in communication, errors due to misinterpretation of drawings, and difficulties in tracking changes across multiple documents (Miettinen & Paavola, 2014).

BIM significantly improves these processes by digitising and centralising project data. For example, instead of relying on multiple sets of physical drawings, BIM provides a single digital model that all stakeholders can access and update as needed. This reduces the risk of discrepancies between different versions of project documentation and ensures that all team members are working with the most up-to-date information (Succar, 2009).

2.2.2 Efficiency Gains with BIM 360

BIM 360 further enhances the digitisation of construction processes by providing tools that streamline collaboration, document management and field execution. For example, BIM 360 Docs eliminates the need for physical document storage and distribution by providing a cloud-based platform where all project documentation is stored, managed and accessed in real time. This not only reduces the time spent handling documents, but also minimises the risk of errors associated with outdated information.

In addition, BIM 360's ability to integrate with mobile devices means that field workers can access project information, report issues, and track progress directly from the site. This level of accessibility was not possible with traditional manual processes, where communication between the office and the site often led to delays and miscommunication (Love et al., 2013). The real-time nature of BIM 360 ensures that project managers can closely monitor progress, address issues as they arise and make adjustments to the project plan as necessary.

2.2.3 Challenges in Transitioning from Manual to Digital Processes

While the benefits of moving from manual to digital processes using BIM and BIM 360 are clear, the process is not without its challenges. One of the main obstacles is the learning curve associated with adopting new technologies. Construction professionals accustomed to traditional methods may require extensive training to become proficient with BIM tools (Miettinen & Paavola, 2014).

In addition, the initial costs of implementing BIM and BIM 360 can be significant, especially for smaller firms with limited resources. This includes the cost of software licences, hardware upgrades and training programmes. Furthermore, resistance to change is a common challenge in the construction industry, where established practices are deeply ingrained and stakeholders may be reluctant to adopt new ways of working (Love et al., 2013).

BIM is having a profound impact on construction project management, offering numerous advantages over traditional manual processes. By improving planning, execution and monitoring through digital tools, BIM and BIM 360 improve collaboration, reduce errors and increase efficiency throughout the project lifecycle. However, the transition from manual to digital processes requires careful management, investment in training and a willingness to embrace change. As the construction industry continues to evolve, BIM and platforms such as BIM 360 will play an increasingly central role in shaping the future of project management.

3. Critical Success Factors in the Implementation of BIM for Digitalization of Construction Processes

3.1 Introduction

Building Information Modeling (BIM) represents a transformative leap forward in the construction industry's journey toward digitalization. As a sophisticated digital tool, BIM enables the comprehensive modeling of the physical and functional characteristics of buildings and infrastructure. This technology facilitates enhanced collaboration among project stakeholders, more efficient project management, and informed decision-making throughout the entire lifecycle of a construction project—from initial design and planning through to operation and maintenance (Smith & Hansen, 2016). The digital models created with BIM are rich with data that can be leveraged to optimize various aspects of construction, including cost estimation, material usage, and timeline scheduling, thus significantly improving project outcomes.

The potential of BIM to revolutionize construction project management is becoming increasingly clear as the industry shifts from traditional, manual processes to more advanced, digital methodologies. This transition is not just about adopting new software; it involves a fundamental change in how projects are managed, emphasizing the integration of all aspects of the construction process into a cohesive, digital framework. The digitization enabled by BIM helps streamline operations by reducing manual errors, improving communication among stakeholders, and providing a more transparent and detailed view of the project at any given stage. Consequently, BIM is recognized not only as a tool for improving the efficiency of construction projects but also as a means to achieve higher levels of accuracy, predictability, and control over project outcomes (Azhar, 2011).

3.1.1 Importance of Identifying Critical Success Factors (CSFs)

Despite the clear benefits of BIM, its successful implementation is not guaranteed. The construction industry, known for its resistance to change and reliance on traditional methods, presents unique challenges in adopting such a transformative technology. This resistance underlines the importance of identifying and understanding the Critical Success Factors (CSFs) that can make or break BIM implementation efforts. CSFs are those essential elements that must be effectively managed to ensure the successful adoption and integration of BIM into construction project management practices.

Identifying these CSFs is critical for several reasons. Firstly, they provide a roadmap for organisations wishing to implement BIM, highlighting the areas that require particular attention and resources. Secondly, CSFs help to anticipate potential challenges and prepare strategies to mitigate them, thereby reducing the risk of failure. Finally, in the context of the ongoing shift from manual to digital processes, understanding CSFs is essential to ensure that BIM not only integrates smoothly into existing workflows, but also enhances them, leading to significant improvements in efficiency, accuracy and overall project performance (Alias et al., 2014).

In addition, the digitisation of manual processes through BIM is increasingly seen as a strategic priority within the construction industry. As organisations seek to remain competitive in a rapidly evolving market, the ability to harness the full potential of BIM is becoming a critical success factor. This involves not only adopting the technology, but also aligning it with broader organisational goals and ensuring that it contributes to the strategic objectives of improving project delivery, reducing costs and enhancing sustainability. The identification and management of CSFs thus becomes a key component of any successful BIM implementation strategy, ensuring that organisations can fully realise the benefits of this powerful technology (Cooke-Davies, 2002).

In summary, the introduction of BIM into construction project management offers significant benefits, but also requires careful consideration of the factors that will determine its success. By focusing on these CSFs, organisations can navigate the complexities of BIM adoption, overcome resistance to change and achieve a smooth transition from manual to digital processes, ultimately leading to more efficient, cost-effective and successful construction projects.

The successful implementation of BIM in construction project management depends on several key factors, including the selection of appropriate technology with strong interoperability and a robust digital infrastructure (technological factors), the need for committed senior management support and effective stakeholder communication (organisational and strategic factors), the importance of continuous training and effective change management (people and skills factors), and the establishment of standardised processes and regulatory frameworks to seamlessly integrate BIM into all project workflows (process and workflow factors). Understanding and managing these elements is essential to navigate the complexities of BIM adoption and ensure that organisations can fully realise the benefits of this transformative technology.

3.1.2 Technological Factors

Technological factors, particularly the selection of appropriate software and ensuring interoperability, together with the establishment of a robust digital infrastructure, are critical to the successful implementation of BIM in construction project management. The process of selecting the right BIM software is not just a technical decision, but a strategic one that has a profound impact on the overall success of the project. The literature emphasises the need to select software that meets the specific technical requirements of the project, while also being compatible with other tools and platforms used by different stakeholders. This compatibility, known as interoperability, is crucial for facilitating effective collaboration between different teams, allowing them to share and access project data seamlessly and without compatibility issues. Without adequate interoperability, projects run the risk of developing data silos - isolated pockets of information that hinder communication and coordination. This can lead to significant challenges such as miscommunication, delays and increased costs as stakeholders struggle to align their work processes and outputs with those of others involved in the project (Czmoch & Pękala, 2014). In addition to software selection, the underlying digital infrastructure plays an equally critical role in the successful implementation of BIM. A robust IT environment is required to support the complex data management and intensive computational tasks associated with BIM software. This infrastructure includes high-performance computing resources, reliable data storage solutions and real-time communication systems, all of which are essential for managing the vast amounts of data generated and used throughout the BIM process (Alias et al., 2014). Studies have shown that without a strong digital infrastructure, the potential benefits of BIM - such as real-time updates, enhanced collaboration and improved decision-making - cannot be fully realised. Inefficiencies may arise, leading to potential project failures, if the infrastructure is unable to support the requirements of BIM software. Therefore, the careful selection of interoperable BIM software, coupled with the establishment of a robust and reliable digital infrastructure, is essential for the effective implementation and operation of BIM in construction projects, ensuring that the full benefits of this transformative technology can be realised.

3.1.3 Organisational and strategic factors

Organisational and strategic factors play a key role in the successful implementation of BIM, with top management support and effective stakeholder engagement among the most critical components. Top management commitment goes beyond simply allocating financial and human resources; it involves actively fostering a culture of innovation and embracing digital transformation within the organisation. When top management is visibly engaged and invested in BIM initiatives, it significantly increases the likelihood of success by aligning these initiatives with the organisation's broader strategic goals. This alignment ensures that BIM adoption is not seen as an isolated technological upgrade, but as a strategic move that supports the overall mission of the organisation, driving efficiency, competitiveness and innovation. Furthermore, studies suggest that the presence of strong leadership at the top level can mitigate resistance to change, a common challenge in the construction industry, thereby facilitating the transition to digital processes (Cooke-Davies, 2002).

In addition to leadership, the success of BIM implementation depends heavily on robust stakeholder engagement and communication. Given the collaborative nature of BIM, which integrates input from multiple disciplines such as architecture, engineering and construction management, it is essential that all stakeholders are consistently and clearly communicated with throughout the project lifecycle. Effective communication ensures that architects, engineers, contractors and clients are all aligned with the project goals and can contribute their expertise without misunderstanding or conflict. This alignment is critical not only for day-to-day operations, but also for strategic decision-making, as it enables a coordinated approach to problem solving and adjustments as the project progresses. Research has shown that projects with well-established communication channels are more likely to succeed in their BIM implementation efforts, as they facilitate smoother decision-making processes and reduce the likelihood of costly errors or delays (Abu-Moeilak et al., 2023). In summary, the strategic commitment of top management, combined with effective stakeholder communication, forms the backbone of a successful BIM implementation, ensuring that the technology is seamlessly integrated into the organisation's operations and aligned with its long-term objectives.

3.1.3 Human Resources factors

Human resources and skills are critical to the successful implementation of BIM, particularly in the areas of training, skills development and change management. The transition to BIM requires significant investment in training and development to ensure that all users have the necessary skills to effectively use the complex tools and software associated with BIM. Given the intricacies of digital modelling and the precision required, inadequate training can lead to significant problems such as errors in BIM models, reduced efficiency and resistance from staff who are more comfortable with traditional methods (Alias et al., 2014). Ongoing training and upskilling is therefore essential, not only to maintain the competence of the workforce, but also to foster a culture of adaptability and openness to technological advances. This ongoing commitment to training helps to mitigate the risks associated with transitioning to new systems and ensures that the organisation can fully realise the benefits of BIM.

In addition to skills development, effective change management is critical to overcoming the inherent resistance to adopting BIM, especially in an industry as traditionally entrenched as construction. Resistance to change is a common barrier to the adoption of new technologies and, if not properly managed, can derail even the most well planned BIM initiatives. Change management strategies must therefore be proactive and include not only comprehensive training, but also the active involvement of employees in the transition process. This approach involves addressing their concerns, communicating clearly about the benefits of BIM, and demonstrating how the new digital workflows will improve their daily tasks and overall project outcomes (Cooke-Davies, 2002). By involving employees in this way, organisations can reduce anxiety and resistance, facilitating a smoother transition from manual processes to more efficient digital workflows. Effective change management, combined with ongoing skills development, therefore plays a crucial role in ensuring that BIM implementation is successful, sustainable and aligned with the organisation's strategic objectives (Abu-Moeilak et al., 2023).

3.1.3 Process and workflow factors

Process and workflow factors are critical to the effective implementation of BIM, particularly in terms of standardisation, legal considerations, sustainability and efficiency. One of the main challenges to the adoption of BIM is the lack of standardised processes and legal recognition, which can hinder its widespread use. Standardisation is essential to ensure that BIM models are consistent, accurate and legally binding at all stages of a project. This uniformity in standards helps to minimise errors, ensures that all stakeholders are working from the same accurate data, and facilitates smoother project delivery (Ulvestad & Vieira, 2021). Furthermore, when BIM is legally recognised as the primary contractual document, it can significantly streamline processes, reduce reliance on traditional 2D drawings, and mitigate the risk of disputes that often arise from discrepancies in documentation. Studies have shown that projects that adopt standardised BIM practices are more likely to be completed on time and within budget, reinforcing the importance of these factors to project success (Smith & Hansen, 2016).

In addition to standardisation, BIM's potential to improve sustainability and efficiency is a key driver for its adoption in the construction industry. BIM provides detailed, accurate models that enable better resource management, which in turn reduces waste and improves the overall efficiency of construction projects. By simulating different scenarios, BIM enables project teams to optimise designs for energy efficiency and environmental impact, contributing to more sustainable construction practices (Abu-Moeilak et al., 2023). This capability not only supports the industry's shift towards greener practices, but also improves the economic viability of projects by reducing costs associated with waste and inefficiency. Standardisation, legal recognition and a focus on sustainability and efficiency are therefore essential to maximising the benefits of BIM in construction project management, ensuring that it can deliver on its promise of improving project outcomes and contributing to the wider goals of sustainable development.

The literature review has highlighted several critical success factors (CSFs) that are essential for the successful implementation of BIM in construction project management, including the selection of appropriate technology such as software and digital infrastructure, the need for strong organisational support from top management, effective stakeholder engagement, continuous training and skills development, and the establishment of standardised processes with legal recognition. These factors are interrelated and together contribute to the efficient adoption and integration of BIM, ensuring that the technology fulfils its potential to improve project outcomes and drive digital transformation in the construction industry.

For practitioners, addressing these CSFs is critical to developing effective BIM implementation strategies that maximise the benefits of digitisation and improve project delivery. Future research should delve deeper into the specific challenges of BIM implementation in different regional and sectoral contexts and provide tailored strategies that address unique local needs and conditions. In addition, there is a growing need to explore the long-term impacts of BIM on sustainability and project efficiency, as well as the development of more advanced interoperability standards to promote wider and more effective adoption of BIM across the industry. By focusing on these areas, future studies can provide valuable insights that will further refine the application of BIM and ensure its role as a cornerstone in the modernisation of construction project management.

3.2 Key Blockers in BIM Implementation

While the benefits of digitising construction processes through BIM and other technologies are well documented, the transition from traditional methods to digital workflows is fraught with challenges. Understanding these challenges is critical to developing strategies to mitigate risk and ensure the success of digital transformation initiatives.

3.2.1 Resistance to Change

One of the most significant challenges of digital transformation is resistance to change within organisations. The construction industry is traditionally conservative, with established practices and workflows that have been in place for decades. The introduction of new technologies such as BIM can be met with scepticism, especially among workers who are more comfortable with manual processes (Miettinen & Paavola, 2014). Overcoming this resistance requires a change management strategy that includes clear communication, leadership buy-in and engagement with employees to address their concerns and demonstrate the value of digital tools (Azhar, 2011).

3.2.2 High Implementation Costs

The cost of implementing BIM and other digital technologies can be a significant barrier, particularly for small and medium-sized enterprises (SMEs) in the construction industry. The initial investment in software, hardware and training can be prohibitive, especially if there is no immediate financial return (Gu & London, 2010). In addition, the cost of ongoing maintenance, updates and support adds to the financial burden. The literature suggests that while the long-term benefits of digital transformation are significant, the high upfront costs can deter organisations from fully committing to these initiatives (Love et al., 2013).

3.2.3 Interoperability Issues

Interoperability, or the ability of different systems and tools to work together seamlessly, is another challenge in the digitisation of construction processes. BIM relies on the integration of different software platforms, each of which may have its own data standards and formats. This can make it difficult to share information between different systems and stakeholders, leading to inefficiencies and potential errors (Eastman et al., 2011). The lack of industry-wide standards for data exchange and software compatibility exacerbates these problems, making it difficult to realise the full collaborative potential of BIM (Succar, 2009).

3.2.4 Data Management and Security

As construction processes become increasingly digitised, the amount of data generated by projects is increasing exponentially. Effectively managing this data, ensuring its accuracy, and protecting it from unauthorised access are critical concerns (Miettinen & Paavola, 2014). BIM involves the storage and exchange of large amounts of sensitive information, including designs, schedules and cost estimates. Ensuring the security of this data requires a robust IT infrastructure and strict data management protocols. However, studies show that many construction companies are not adequately prepared to meet these challenges, leaving them vulnerable to data breaches and other security risks (Gu & London, 2010).

3.2.5 Skill Gaps and Training Needs

The shift to digital construction processes requires a workforce with new skills and competencies. However, there is often a gap between the skills required for effective BIM implementation and the current capabilities of the construction workforce (Azhar, 2011). This gap can lead to inefficiencies and errors, as workers struggle to adapt to new technologies without adequate training and support. The literature highlights the importance of continuous learning and development programmes to bridge this gap and ensure that staff are equipped to meet the demands of digital construction (Love et al., 2013).

3.2.6 Cultural and Organizational Barriers

The successful adoption of digital tools in construction often requires a cultural shift within the organisation. This involves moving away from traditional hierarchical structures to more collaborative and integrated ways of working (Miettinen & Paavola, 2014). However, organisational culture can be deeply entrenched, making it difficult to implement the changes required for digital transformation. Research suggests that fostering a culture of innovation and flexibility is key to overcoming these barriers, but this requires sustained effort and commitment from leadership (Gu & London, 2010).

The digitalisation of construction processes, particularly through the use of BIM, offers significant benefits but also poses a number of challenges. The successful implementation of digital tools requires the identification and management of key success factors, such as top management support, a well-defined strategic vision and active stakeholder involvement. However, overcoming barriers such as resistance to change, high implementation costs and interoperability issues requires careful planning, investment and a commitment to continuous improvement. As the construction industry continues to evolve, these elements will be critical in shaping the future of digital project management.

However, the existing literature does not provide a comprehensive set of critical success factors (CSFs), nor a thorough evaluation of their impact on the implementation of BIM in construction project management, particularly when it comes to digitising manual processes. For this reason, the analysis presented in the following chapters is necessary.

4. Methodology

4.1 Academic Literature Review and Criteria Identification

First, a comprehensive literature review was conducted to identify the critical success factors (CSFs) for the successful implementation of Building Information Modelling (BIM) in construction project management, with a particular focus on the digitisation of manual processes. This review used the Scopus, ASCE and Google Scholar libraries to collect the most relevant academic literature on BIM implementation, construction project management practices and the challenges associated with digital transformation in the industry. The collection and screening phases resulted in the identification of 28 key sources that were considered essential for the purposes of this research.

The general review of BIM implementation practices and the broader context of construction project management provided a fundamental understanding of the objectives and challenges associated with digitising construction processes. This understanding was critical to the subsequent analysis of the critical success factors that are integral to ensuring the effective adoption of BIM technologies. Consequently, the review focused on identifying the specific factors identified in the literature as critical to the success of BIM projects, particularly those involving the transition from manual to digital workflows.

The literature review was further refined to focus on the criteria and factors most commonly identified as essential for successful BIM implementation. The literature review was further refined to focus on the criteria and factors most commonly identified as essential for successful BIM implementation. These criteria were also discussed with industry professionals to ensure practical relevance and to gain insights from their real-world experiences, further enriching the analysis and applicability of the findings.

These factors were then systematically categorised to form a comprehensive framework that could guide the evaluation of BIM initiatives. This framework served as the basis for the questionnaire, which was distributed to a selected group of construction experts who provided insight and validation of the identified CSFs. The data collected was then analysed using established methodologies, as described in the following sections, to ensure that the identified success factors were both relevant and applicable in real-world scenarios.

4.2 Analytical Hierarchy Process (AHP) Method and Criteria Weighting

In order to effectively prioritise and weight the criteria identified in the literature review, the Analytical Hierarchy Process (AHP) was selected as the multi-criteria decision making methodology. AHP is particularly well suited to complex decision contexts, such as those encountered in the implementation of BIM for construction project management, due to the following key attributes

- **Multi-Attribute Decision-Making (MADM):** AHP is recognised as a powerful tool within the category of multi-criteria decision making (MCDM) methods, making it ideal for addressing selection and prioritisation challenges in scenarios where multiple factors need to be considered simultaneously (Ishizaka & Labib, 2011).
- **Structured and Systematic Approach:** The AHP method provides a clear, well-structured and systematic process that is flexible enough to be adapted to different decision-making contexts. It is widely used in project management because it simplifies complex decisions into manageable components (Vidal et al., 2015).
- **Integration of Qualitative and Quantitative Data:** One of AHP's strengths is its ability to combine both qualitative judgement and quantitative data, which is essential for managing the subjective and complex aspects of BIM implementation and construction project management.
- **Hierarchical Structure:** AHP organises decision elements into a hierarchy, allowing decision makers to break the problem down into smaller, more manageable parts. This hierarchy facilitates a deeper understanding of the relationships between different criteria (Vargas et al., 1990).
- **Pairwise Comparisons:** The method involves making pairwise comparisons between criteria, allowing decision-makers to assess the relative importance of each criterion. This step results in a matrix of comparisons, which is then analysed to calculate the relative weights of the criteria using the eigenvalue method (Saaty, 2004).

- **Consistency and Coherence:** AHP includes mechanisms to check the consistency of judgments made during pairwise comparisons, ensuring that the resulting criteria weights are logically sound and coherent.
- **Synthesis of Results:** After determining the weights for each criterion, AHP synthesises these results to establish the overall priorities. This process ensures that the final decision reflects the cumulative importance of each criterion across all levels of the hierarchy.

The AHP method is implemented in two main phases:

1. **Design Phase:**
    - **Hierarchy Construction:** Identify and organise the decision elements into a hierarchical structure.
    - **Concept Definition:** Clarify the concepts and criteria that will guide the decision-making process.
    - **Question Formulation:** Develop the questions that will be used to perform pairwise comparisons.
2. **Evaluation Phase:**
    - **Pairwise Comparisons:** Conduct pairwise comparisons for each criterion to determine their relative importance.
    - **Weight Calculation:** Use the eigenvalue method to calculate the weights of each criterion based on the comparisons.
    - **Priority Determination:** Aggregate the weights to determine the overall priority of each element in the hierarchy.

The robustness and effectiveness of the AHP methodology makes it an invaluable tool for decision-makers in the construction industry, particularly when addressing the complex challenges associated with BIM implementation. Its ability to provide a clear, structured and consistent approach to evaluating multiple criteria ensures that final decisions are both well informed and strategically sound.

4.3 Data Collection and Analytical Hierarchy Process (AHP) Application

The Analytical Hierarchy Process (AHP) was applied in this study to assess and prioritize the relevant criteria for digital transformation projects. AHP provides a mathematical framework for structuring complex decisions, comparing multiple criteria and alternatives based on expert judgments. Several formulas were used to derive important decision metrics, including Composite Global Importance (CGI), weighted criterion scores (C_{ij}), and final ranking scores (S*) for the alternatives.

Professional Selection Criteria

The selection of professionals was based on the following criteria to ensure relevant and accurate data:

- At least 5 years of experience in the Construction Industry.
- Experience in both Construction and Pre-Construction phases.
- Currently working in Europe, with familiarity in European standards and regulations.
- Actively involved in large-scale projects within large organizations.
- A career spanning more than one company to ensure diverse perspectives.

Pairwise Comparison Process and Criterion Weights

For the pairwise comparison process, the experts were asked to evaluate the relative importance of each pair of criteria using the Saaty scale, which assigns values based on the following interpretations:

- **1**: Criteria C_i and C_j are of equal importance.
- **3**: C_i is slightly more important than C_j.
- **5**: C_i is moderately more important than C_j.
- **7:** C_i is strongly more important than C_j.
- **9:** C_i is extremely more important than C_j.

Intermediate values of **2**, **4**, **6**, and **8** are used for compromise judgments when the importance is between two levels on the scale.

Constructing the Pairwise Comparison Matrix

After collecting the expert judgments, a pairwise comparison matrix A is constructed. Each element a_{ij} in the matrix represents the relative importance of criterion C_i compared to criterion C_j. The matrix is structured as follows:

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \cdots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \cdots & 1 \end{pmatrix}$$

The diagonal elements of the matrix are always 1, as each criterion is equally important as itself. The reciprocal property ensures consistency, meaning that if aij= x, then aji =x1

Calculating the Priority Weights

Once the pairwise comparison matrix is constructed, the next step is to calculate the priority weight vector w=[w1,w2,...,wn] w = [w_1, w_2, ..., w_n] w=[w1,w2,...,wn], which gives the relative importance of each criterion. This is achieved by normalizing the matrix and computing the average of the rows. To normalize the matrix, each element of a column is divided by the sum of its column values. The normalized values are then used to compute the priority weight for each criterion by averaging the row values:

$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{n}$, for each i = 1,2,...,n

This priority weight vector represents the relative importance of each criterion, and the sum of all weights equals 1.

Consistency Check: Consistency Index (CI) and Consistency Ratio (CR)

To ensure the consistency of expert judgments, we calculate the **Consistency Index (CI)** as follows:

$$CI = \frac{\lambda_{max} - N}{N - 1}$$

The **Consistency Ratio (CR)** is then calculated by comparing the CI to a random index (RI), which is the average CI of randomly generated matrices. The formula for CR is:

$$CR = \frac{CI}{RI}$$

A CR value below 0.1 indicates acceptable consistency, while a higher CR suggests that the expert judgments need to be revisited to reduce inconsistency.

Composite Global Importance (CGI)

The Composite Global Importance (CGI) is calculated to assess the overall importance of each criterion within the global hierarchy. The formula for CGI is as follows:

$$CGI = \frac{2\sum_{i<j} \ln a_{ij} - \ln \frac{p_i}{p_j}}{(N-1)(N-2)}$$

Where:

- aij are the pairwise comparison values,
- p_i and p_j are the priority weights for criteria C_i and C_j,
- N is the number of criteria.

This formula incorporates both the logarithmic differences between pairwise comparisons and the relative weights of criteria, giving a comprehensive view of the global importance of each criterion.

Weighted Criterion Scores (C_{ij})

The next step is to compute the weighted criterion scores C_{ij}, which capture the aggregated comparison results for each criterion. The formula is:

$$C_{ij} = \exp\left(\frac{\sum_{k=1}^{N} w_k \ln a_{ij(k)}}{\sum_{k=1}^{N} w_k}\right)$$

Where:

- $a_{ij(k)}$ represents the comparative judgment of C_i relative to C_j by expert kkk,
- w_k is the weight associated with each expert's judgment.

This formula takes into account the weighted input from all experts, leading to a more precise calculation of the relative importance of each criterion.

Final Ranking Scores (S*)

Finally, the global score (S*) for each alternative is calculated using the following formula:

$$S^* = \left[M - \frac{\exp(H_{\alpha_{\min}})}{\exp(H_{\gamma_{\max}})}\right]\left[1 - \frac{\exp(H_{\alpha_{\min}})}{\exp(H_{\gamma_{\max}})}\right]$$

Where:

- $H_{\alpha_{min}} and\ H_{\gamma_{max}}$ represent the minimum and maximum logarithmic values for certain criteria across all comparisons,
- H_{β} serves as a balancing factor.

This formula ranks the alternatives based on their performance relative to the weighted criteria, with the highest S* score representing the best alternative.

5. Application of the AHP method

The primary objective of this research is to identify and prioritise the Critical Success Factors (CSFs) for the successful implementation of Building Information Modelling (BIM) in construction project management, with a focus on the digitisation of manual processes. As the adoption of BIM becomes more widespread in the construction industry, understanding the key factors that lead to successful implementation is critical to ensuring that projects meet their objectives and fully realise the potential of BIM technology.

To achieve this, a systematic review of 28 academic articles was conducted. These articles focus on the implementation of BIM within construction project management and provide insights into the key challenges, opportunities and success factors associated with BIM adoption. The review covered different industries, time periods and perspectives to ensure a comprehensive understanding of the factors influencing successful BIM implementation.

In addition to the literature review, this research benefited from the insights of professionals with significant experience in the construction industry. These professionals provided practical perspectives on the implementation challenges they have encountered, helping to refine and validate the findings from the academic literature.

Based on the review and professional input, six macro-categories were identified, each containing a total of 18 specific criteria. These criteria cover a wide range of factors critical to the successful implementation of BIM, including technology integration, organisational change management, regulatory compliance, process improvement and more. These criteria provide a structured framework for understanding and addressing the key areas that need to be managed for successful BIM adoption.

The next step was to organise these criteria into a hierarchical structure to facilitate the use of the Analytical Hierarchy Process (AHP). The AHP method allows weights and priorities to be assigned to each criterion, ensuring that the most critical factors receive the appropriate attention in the decision-making processes associated with BIM implementation. The AHP analysis, supported by expert insight, ensures that these criteria are not only theoretically robust, but also practically applicable.

The following section focuses on the data collection and calculation processes used in the AHP analysis, where the criteria were evaluated and prioritised. However, the emphasis in this section is on the identification and structuring of the criteria, which serves as the basis for the broader analysis of the success factors for BIM implementation.

This approach ensures that the CSFs identified in this research are both grounded in academic literature and validated by real-world experience, providing a practical framework for stakeholders involved in the implementation of BIM in construction projects.

Below it's possible to identify the 18 criteria with their respective sources from the academic literature:

Criteria Identified	Source from Academic Literature
Compatibility with Existing IT Infrastructure:	Grilo & Jardim-Goncalves (2010), Sackey et al. (2013), Wu, K., & Tang, S. (2022), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Sepasgozar et al. (2021), Abdelalim et al. (2024), Al Hattab & Hamzeh (2015), Domingues & Santos (2021), Semaan et al. (2021), Azhar et al. (2008), Motawa & Almarshad (2013), AbuMoeilak et al. (2023), Rajabi et al. (2022), Cavka et al. (2015), Ahmed et al. (2024), Borghoff et al. (2024), Eastman et al. (2009), Malsane et al. (2015)
Ease of Integration with Current Workflows:	Sackey et al. (2013), Staub-French, S., & Poirier, E. (2023), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Al Hattab & Hamzeh (2015), Sacks & Koskela (2010), Semaan et al. (2021), Azhar et al. (2008), Isikdag (2010), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), MacLoughlin & Hayes (2019), Rajabi et al. (2022), Ahmed et al. (2024)
Interoperability with Other Tools and Systems:	Shirowzhan et al. (2020), Sackey et al. (2013), Staub-French, S., & Poirier, E. (2023), Sepasgozar et al. (2021), Motawa & Almarshad (2013), Becerik-Gerber et al. (2012), AbuMoeilak

	et al. (2023), Ahmed et al. (2024), Borghoff et al. (2024), Lee et al. (2019), Malsane et al. (2015)
Capability to Streamline Workflow	Grilo & Jardim-Goncalves (2010), Shirowzhan et al. (2020), Wu, K., & Tang, S. (2022), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Sepasgozar et al. (2021), Bortolini (2019), Al Hattab & Hamzeh (2015), Domingues & Santos (2021), Azhar et al. (2008), Motawa & Almarshad (2013), Becerik-Gerber et al. (2012), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), Lee et al. (2019)
Reduction in Process Time	Grilo & Jardim-Goncalves (2010), Wu, K., & Tang, S. (2022), Staub-French, S., & Poirier, E. (2023), Bortolini (2019), Abdelalim et al. (2024), Sacks & Koskela (2010), Isikdag (2010), AbuMoeilak et al. (2023), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), Rajabi et al. (2022)
Improvement in Data Accuracy and Reduction of Errors	Grilo & Jardim-Goncalves (2010), Shirowzhan et al. (2020), Wu, K., & Tang, S. (2022), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Sepasgozar et al. (2021), Abdelalim et al. (2024), Sacks & Koskela (2010), Semaan et al. (2021), Isikdag (2010), Motawa & Almarshad (2013), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), Cavka et al. (2015), Ahmed et al. (2024), Borghoff et al. (2024), Lee et al. (2019)
Availability of Training Resources	Sackey et al. (2013), Staub-French, S., & Poirier, E. (2023), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Semaan et al. (2021), AbuMoeilak et al. (2023), MacLoughlin & Hayes (2019)

User-Friendliness of the BIM Software	Azhar et al. (2008), Isikdag (2010)
Support and Maintenance Services Provided	Motawa & Almarshad (2013), Becerik-Gerber et al. (2012)
Management Support for BIM Initiatives	Grilo & Jardim-Goncalves (2010), Staub-French, S., & Poirier, E. (2023), Bortolini (2019), Al Hattab & Hamzeh (2015), Domingues & Santos (2021), Azhar et al. (2008), Motawa & Almarshad (2013), Becerik-Gerber et al. (2012), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), Cavka et al. (2015), Succar & Kassem (2015), Ahmed et al. (2024)
Strategies to Overcome Resistance to Change	Sackey et al. (2013), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Semaan et al. (2021), MacLoughlin & Hayes (2019), Rajabi et al. (2022)
Alignment of BIM Strategy with Organizational Goals	Shirowzhan et al. (2020), Wu, K., & Tang, S. (2022), Sepasgozar et al. (2021), Sacks & Koskela (2010), Domingues & Santos (2021), Azhar et al. (2008), Isikdag (2010), Motawa & Almarshad (2013), Becerik-Gerber et al. (2012), AbuMoeilak et al. (2023), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), MacLoughlin & Hayes (2019), Cavka et al. (2015), Succar & Kassem (2015), Ahmed et al. (2024)
Contribution to Strategic Objectives	Grilo & Jardim-Goncalves (2010), Sackey et al. (2013), Wu, K., & Tang, S. (2022), Staub-French, S., & Poirier, E. (2023), Bortolini (2019), Al Hattab & Hamzeh (2015), Sacks & Koskela (2010), Domingues & Santos (2021), Semaan et al. (2021), Isikdag (2010), Motawa & Almarshad (2013), Becerik-Gerber et al. (2012), Chan, D. W.

	M., Olawumi, T. O., & Ho, A. M. L. (2019), Rajabi et al. (2022)
Impact on Competitive Advantage	Shirowzhan et al. (2020), Sackey et al. (2013), Staub-French, S., & Poirier, E. (2023), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Sepasgozar et al. (2021), Abdelalim et al. (2024), Semaan et al. (2021), AbuMoeilak et al. (2023)
Long-term Value Creation	Sackey et al. (2013), Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022), Sepasgozar et al. (2021), Abdelalim et al. (2024), Semaan et al. (2021), AbuMoeilak et al. (2023), Rajabi et al. (2022), Cavka et al. (2015), Succar & Kassem (2015), Borghoff et al. (2024)
Compliance with Industry Standards and Regulations	Grilo & Jardim-Goncalves (2010), Wu, K., & Tang, S. (2022), Staub-French, S., & Poirier, E. (2023), Sepasgozar et al. (2021), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), Cavka et al. (2015), Ahmed et al. (2024), Eastman et al. (2009), Lee et al. (2019), Malsane et al. (2015)
Ability to Adapt to Changes in Legal Requirements	Succar & Kassem (2015)
Support for Documentation and Audit Trails	Grilo & Jardim-Goncalves (2010), Wu, K., & Tang, S. (2022), Sepasgozar et al. (2021), Bortolini (2019), Al Hattab & Hamzeh (2015), Domingues & Santos (2021), Azhar et al. (2008), Isikdag (2010), Becerik-Gerber et al. (2012), AbuMoeilak et al. (2023), Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019), Cavka et al. (2015), Borghoff et al. (2024), Eastman et al. (2009), Lee et al. (2019)

5.1 Criteria identification from Critical Success Factors in academic literature

The criteria identified in this research have the primary objective of facilitating the successful implementation of BIM to digitise manual processes in construction project management. The 18 criteria influence different aspects of BIM success and are therefore organised in a hierarchical structure. These criteria are grouped into six macro categories, each representing a key area that contributes to the overall success of BIM implementation. It is important to note that these categories address not only individual project success, but also strategic objectives and organisational benefits. By grouping the criteria into these macro categories, it becomes possible to comprehensively evaluate BIM implementation across multiple dimensions of success.

The six macro categories that form the basis of this hierarchy are

1. **Process Improvement and Efficiency**: This category includes factors related to streamlining workflows, reducing process times and improving data accuracy. These aspects have a direct impact on the operational efficiency of construction projects and contribute to BIM's productivity gains.

2. **Strategic and Value Alignment**: This category focuses on the alignment of BIM initiatives with the strategic objectives of the organisation. It includes criteria related to contributing to long-term value creation, impacting on competitive advantage, and ensuring that BIM projects are aligned with the broader goals of the organisation.

3. **Technology and Integration**: This category covers the technological aspects of BIM implementation, such as compatibility with existing IT infrastructure, ease of integration with current workflows and interoperability with other tools and systems. Successful technology integration is a key enabler for BIM adoption.

4. **Organizational Change Management**: This category addresses the management support required for BIM initiatives and strategies to overcome resistance to change. It also includes the alignment of BIM strategies with organisational goals, highlighting the importance of leadership and organisational readiness.

5. **Regulatory and Compliance**: Compliance with industry standards, the ability to adapt to changes in regulatory requirements, and support for documentation and

audit trails are critical factors in this category. Ensuring that BIM projects comply with legal and regulatory frameworks is essential to their long-term success.

6. **User Training and Support**: This category focuses on the availability of training resources, the ease of use of BIM software, and the support and maintenance services provided. Adequate training and ongoing support ensure that users can effectively implement and maintain BIM systems.

These six macro categories form the first level of the hierarchical structure. At the second level, the 18 identified criteria are grouped under their respective categories, providing a detailed framework for the success of BIM implementation. The hierarchy allows for a structured assessment of how each criterion and category contributes to the overall success of BIM in digitising construction processes.

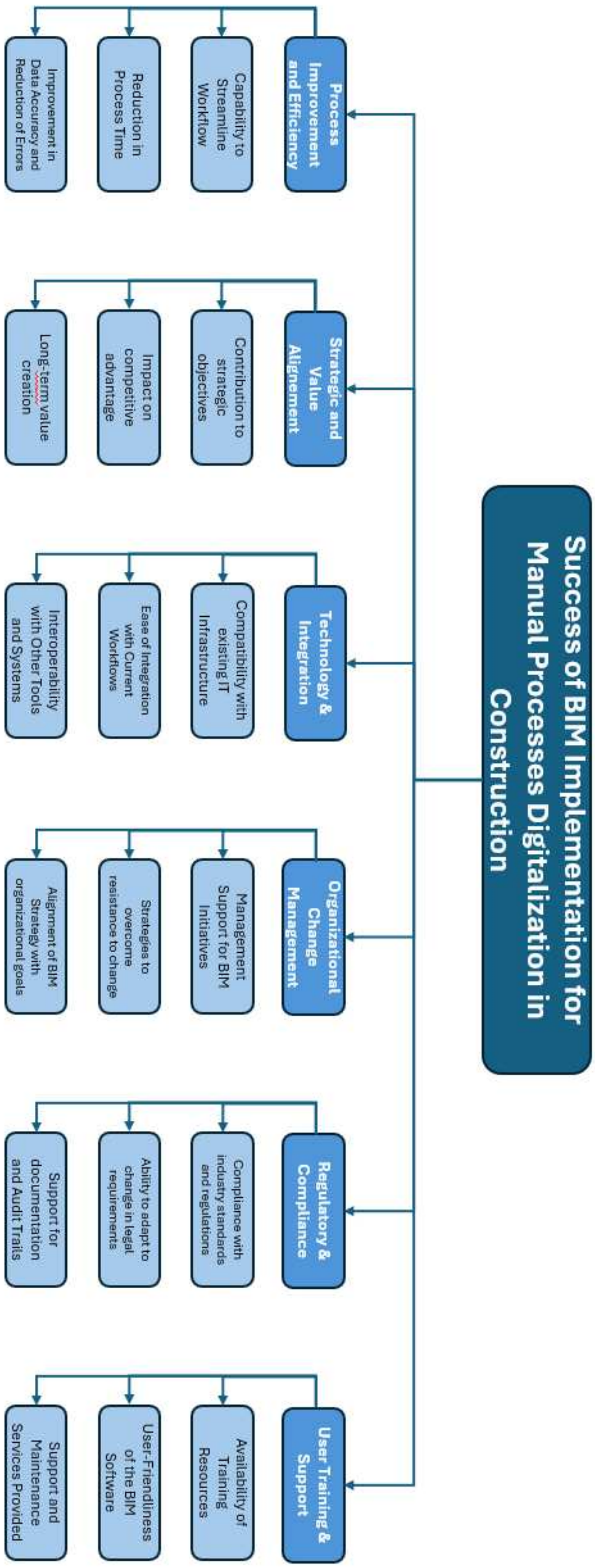

Figure 1. AHP Hierarchy

For each criterion, an ordinal scale can be proposed to better link each element to its practical application. After applying the AHP method, each criterion is assigned a weight that indicates its contribution to the overall success of BIM implementation. This enables decision-makers to assess the value of implementation by using the ordinal scales for each criterion and multiplying the assigned values by the weights determined by the AHP analysis.

The following table provides a description of each specific criterion along with a proposed ordinal scale from 1 to 5 that can be used to evaluate the future digitisation of processes through BIM, once the weights for each criterion have been established using the AHP method. It is important to note that the meaning of each value in the ordinal scale can be adapted by managers and decision makers during the evaluation process to better suit the specific needs and priorities of their organisation.

Success Factors	**Description**	**Proposed Indicator and scale (from 1 to 5)**
Compatibility with Existing IT Infrastructure:	Measures how well the BIM system can be integrated with the organization's current technology setup without extensive modifications.	1: Major modifications needed 3: Some modifications needed 5: Seamless integration with existing infrastructure
Ease of Integration with Current Workflows:	Assesses how simply BIM can be incorporated into existing operational procedures without significant disruption.	1: High disruption (e.g., >40% process changes needed) 3: Moderate disruption (e.g., 20% process changes) 5: Smooth integration (<5% disruption)
Interoperability with Other Tools and Systems:	Evaluates the ability of BIM to exchange data and operate	1: Poor interoperability (e.g., less than 30% compatibility with tools)

	effectively with other software systems and construction tools.	3: Partial interoperability (e.g., 50-70% compatibility) 5: Full interoperability (90-100%)
Capability to Streamline Workflow	Focuses on the ability of BIM to make construction processes more streamlined, thereby enhancing operational efficiency.	1: Low improvement (e.g., <10% efficiency improvement) 3: Moderate improvement (e.g., 10-20% efficiency improvement) 5: High efficiency (>30% improvement)
Reduction in Process Time	Concerns the extent to which BIM can reduce the overall time required for project completion.	1: No time reduction 3: Moderate reduction (e.g., 10-20% reduction in project completion time) 5: Significant reduction (e.g., >30% time reduction)
Improvement in Data Accuracy and Reduction of Errors	Looks at the effectiveness of BIM in enhancing the accuracy of project data and minimizing manual errors.	1: Low accuracy improvement (e.g., <10% error reduction) 3: Moderate improvement (e.g., 20-30% error reduction) 5: High accuracy (>40% error reduction)
Availability of Training Resources	Refers to the accessibility and comprehensiveness of training materials and programs designed to	1: No training available 3: Limited training resources

	equip users with the skills needed to utilize BIM effectively.	5: Comprehensive and accessible training
User-Friendliness of the BIM Software	Measures how intuitive and easy the BIM software is to operate, facilitating smoother adaptation by users.	1: Difficult to use 3: Somewhat user-friendly 5: Very user-friendly and intuitive
Support and Maintenance Services Provided	Assesses the extent and quality of ongoing technical support and maintenance services that ensure the BIM system operates reliably.	1: No support 3: Limited support (e.g., response times >48 hours) 5: Comprehensive support (e.g., response times <24 hours, 24/7 service)
Management Support for BIM Initiatives	Measures the level of backing and resources allocated by upper management for the adoption and integration of BIM.	1: No management involvement 3: Limited involvement 5: Full support
Strategies to Overcome Resistance to Change	Assesses the effectiveness of strategies implemented to manage and mitigate resistance from employees adapting to BIM.	1: No strategies 3: Some strategies in place 5: Well-implemented strategies to overcome resistance
Alignment of BIM Strategy with Organizational Goals	Evaluates how well the BIM implementation aligns with the broader strategic objectives of the organization.	1: No alignment 3: Partial alignment (e.g., 50% of the organization's goals supported) 5: Full alignment (>90% of organizational goals)

Contribution to Strategic Objectives	Measures how the adoption of BIM aligns with and supports the organization's long-term strategic goals, such as increased efficiency, innovation, or market competitiveness.	1: No contribution 3: Moderate contribution (e.g., supports 50% of objectives) 5: Significant contribution (>90% of strategic objectives supported)
Impact on Competitive Advantage	Assesses how BIM enhances the organization's position against competitors, such as through improved project delivery times, cost savings, or enhanced service quality.	1: No impact 3: Moderate impact 5: Significant impact on competitive advantage
Long-term Value Creation	Evaluates the potential of BIM to contribute to sustained value creation for the organization, beyond immediate project outcomes, by enabling new capabilities or markets.	1: Low value creation 3: Moderate value (e.g., ROI in 1-2 years) 5: High long-term value (>3 years sustained ROI)
Compliance with Industry Standards and Regulations	Evaluates how well the BIM implementation adheres to relevant industry standards and legal regulations, ensuring legal compliance and avoiding potential liabilities.	1: Non-compliant 3: Partial compliance (e.g., meets 50-70% of regulatory requirements) 5: Fully compliant (meets all regulatory standards)
Ability to Adapt to Changes in Legal Requirements	Measures the flexibility of the BIM system to accommodate changes in laws and regulations, which can vary by geographical location and over time.	1: Low adaptability 3: Moderate adaptability (e.g., <6 months adaptation time) 5: High adaptability (e.g.,

		<1 month adaptation time)
Support for Documentation and Audit Trails	Assesses the capability of BIM to provide thorough documentation and audit trails that support compliance and quality assurance processes.	1: Poor documentation 3: Moderate documentation 5: Full support (e.g., >90% compliance with audit requirements)

5.2 Professionals Identification and Data Collection

In order to carry out the data collection for the AHP method, a group of experienced professionals were invited to provide their judgements through the pairwise comparisons required by the analysis. A survey was created using Google Forms to facilitate the process and collect the necessary data.

The survey began with a clear description of the overall project, explaining the purpose of the analysis and the role of the respondents' answers. Next, the dimensions of success and the hierarchical structure were outlined to ensure that participants understood how the criteria were grouped. This allowed the professionals to express their judgements on the pairwise comparisons of the main dimensions using Saaty's 1-9 scale (Saaty, 2004).

In addition, within each dimension, the proposed criteria were clearly defined so that participants could make consistent pairwise comparisons between criteria, ensuring clarity and precision in their responses.

The selection of professionals was guided by specific criteria to ensure that experienced individuals were included in the survey. Invitations were sent to 40 professionals with decision-making roles related to construction projects and digital transformation of processes. The surveyed professionals held various leadership and management positions in the construction industry, including roles related to construction management, pre-construction planning, technical oversight and project feasibility.

Of the 40 professionals contacted, 31 responded to the survey, giving a response rate of 78%. All participants were from the construction sector, ensuring that the judgements collected were directly relevant to the digitalisation of construction management processes. This high response rate and the different roles of the participants provided a solid basis for the application of the AHP method, where the weight of each criterion was calculated based on the input of the professionals.

The diversity of professional experience within the construction sector ensured a balanced set of insights, contributing to the robustness of the AHP analysis and supporting the identification of key success factors for BIM implementation.

The breakdown of roles covered by the survey respondents is shown in the pie chart below:

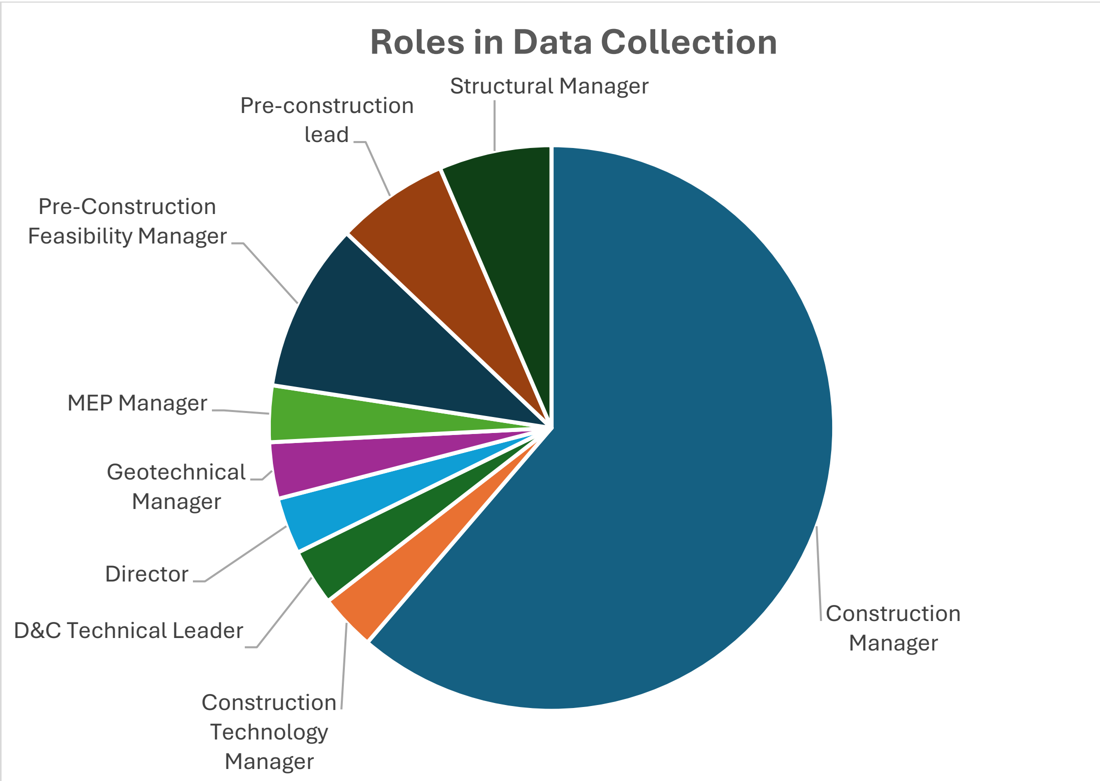

Figure 2. Roles of the survey respondents

Another notable characteristic of the respondents is the diverse range of countries in which they have worked throughout their careers. Collectively, the 31 respondents have gained experience in a total of 26 different countries, with the UK, Spain, Italy, and Luxembourg being the most frequently mentioned. This international exposure adds valuable depth to the data, as it reflects a broad understanding of various working practices and approaches in different regions. Consequently, the respondents' insights are enriched by their familiarity with diverse construction environments, making the data more comprehensive and insightful for this analysis.

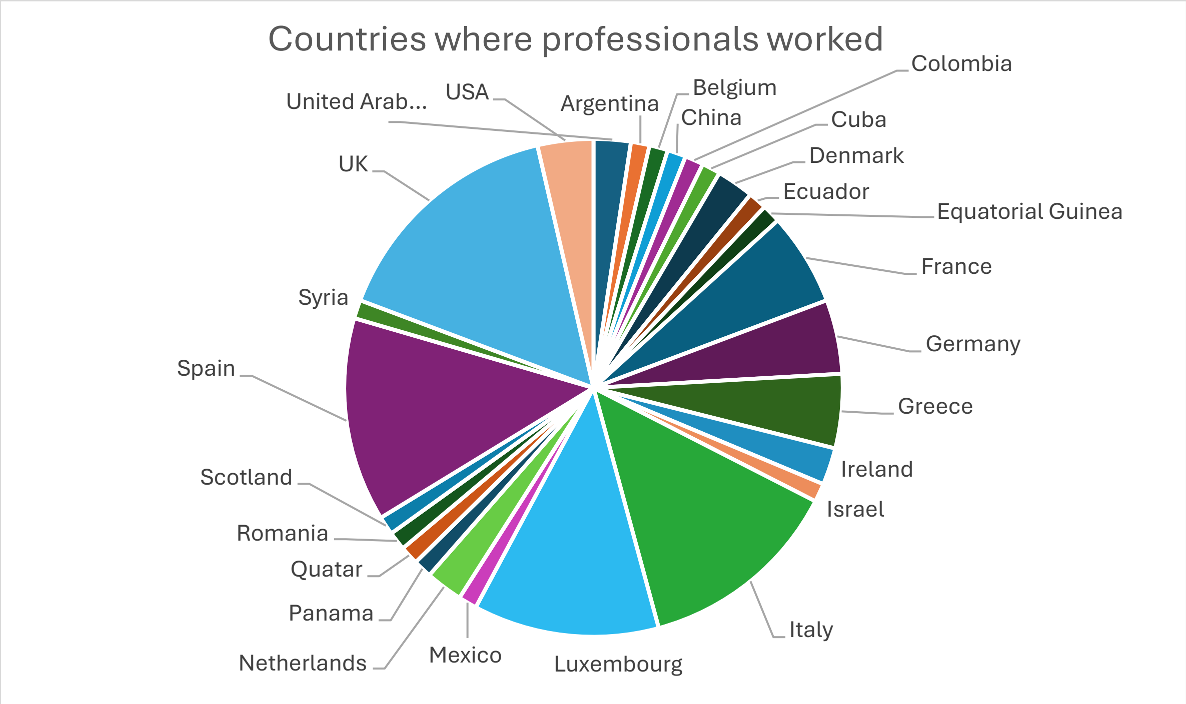

Figure 3.Countries where respondents worked

5.3 Weights assignment and main results

The data collected from the expert judgments were entered into an Excel model following the AHP method, as outlined by Goepel (2013). A total of seven worksheets were used to organise the data and carry out the eigenvalue method, which is an integral part of AHP. These worksheets dealt with the analysis for the main dimensions of success and the four subgroups: organisational factors, human factors, project factors and uncertainty factors, ensuring a structured and accurate application of the AHP process.

Starting with the first level of the hierarchy, which analysed the six success dimensions, the results showed an overall consistency ratio of 1.6%, well within the generally accepted threshold of 10%. This reflects a high degree of consistency in the judgements made. However, the consensus indicator was 37.29%, which is not particularly high, suggesting that there was some variation in the experts' opinions. The following table and graph show the final results for the first level of the hierarchy:

Process Improvement & Efficiency Dimension	Weights	+/-	Ranking
Strategic Value & Alignment	0,259	0,051	1
Process Improvement & Efficiency	0,251	0,050	1
Technology & Integration	0,150	0,034	3
Organizational Change Management	0,142	0,025	3
Regulatory & Compliance	0,105	0,017	5
User Training & Support	0,093	0,021	6

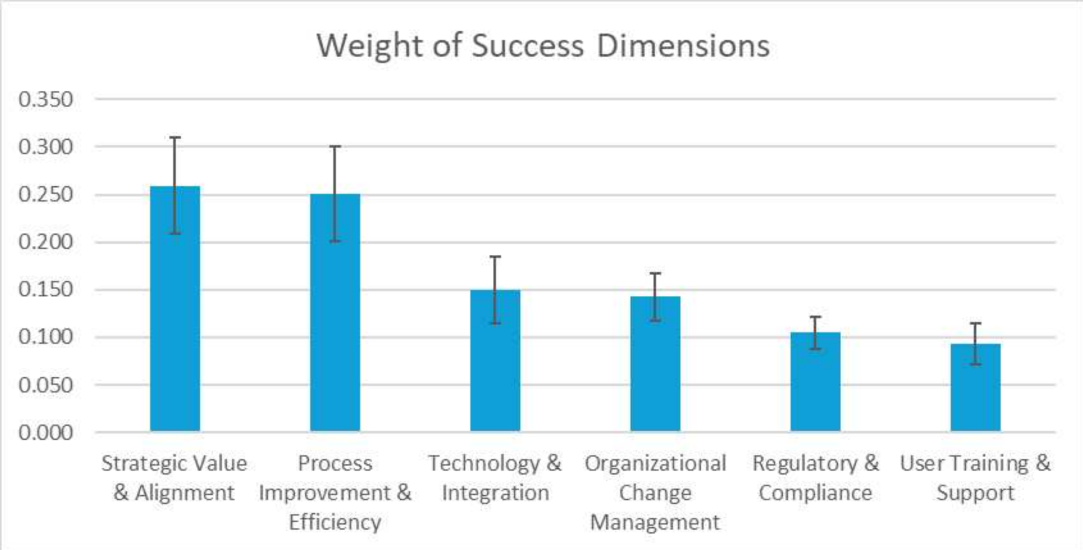

Figure 4. Resulted weights of success dimensions

The top two criteria, Strategic Value & Alignment and Process Improvement & Efficiency, ranked highest with almost equal weightings of 25.9% and 25.1% respectively. This suggests that these two factors are considered by the experts to be the most critical in the context of process improvement. The error intervals for these criteria are also very close, indicating a strong consensus among respondents about their importance.

These are followed by Technology & Integration and Organisational Change Management, with weights of around 15% and 14.2% respectively. Although ranked slightly lower, these criteria still play a significant role in the success of BIM implementation, particularly in terms of securing the technological infrastructure and effectively managing organisational change. However, it is important to note that the error ranges for these criteria overlap slightly, making it difficult to definitively rank one above the other.

The last two criteria, Regulatory & Compliance and User Training & Support, have the lowest weights at 10.5% and 9.3% respectively. While these factors are still critical to successful BIM implementation, they are considered slightly less critical than the other criteria. The relatively small error intervals for these criteria suggest a moderate level of consensus among the experts regarding their importance.

The analysis of the Strategic Value & Alignment dimension showed a Consistency Ratio (CR) of 9.9%, providing a reasonable level of confidence in the results. In addition, the Consensus indicator reached 72.6%, indicating a high level of agreement among the experts surveyed.

Strategic Value & Alignment Dimension	Weights	+/-	Ranking
Contribution to strategic objectives	0,404	0,122	1
Impact on competitive advantage	0,337	0,102	2
Long-term value creation	0,259	0,078	3

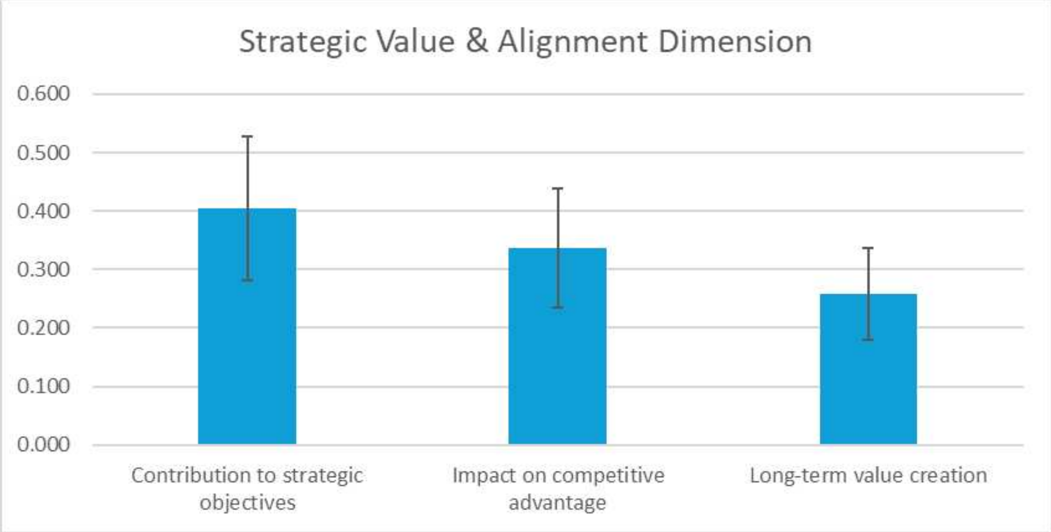

Figure 5. Resulted weights of Strategic Value & Alignment Dimension

Within this dimension, Contribution to strategic objectives emerged as the most important factor with a weight of 40.4%, well above the other criteria. The second most important factor is impact on competitive advantage, with a weight of 33.7%. The final factor, long-term value creation, was still important but ranked lowest with a weight of 25.9%. The results suggest that while all three factors are relevant to strategic value, alignment with a company's strategic objectives is seen as the most critical to success.

Continuing with the Process Improvement & Efficiency dimension, the results showed an excellent consistency ratio of 0.9%, well below the generally accepted threshold of 10%, confirming the reliability of the judgments. Additionally, the consensus level among the experts was high, at 79.2%, indicating strong agreement in the evaluations.

The following table and graph present the final results:

Process Improvement & Efficiency Dimension	Weights	+/-	Ranking
Capability to Streamline Workflow	0,428	0,040	1
Reduction in Process Time	0,323	0,030	2
Improvement in Data Accuracy and Reduction of Errors	0,249	0,023	3

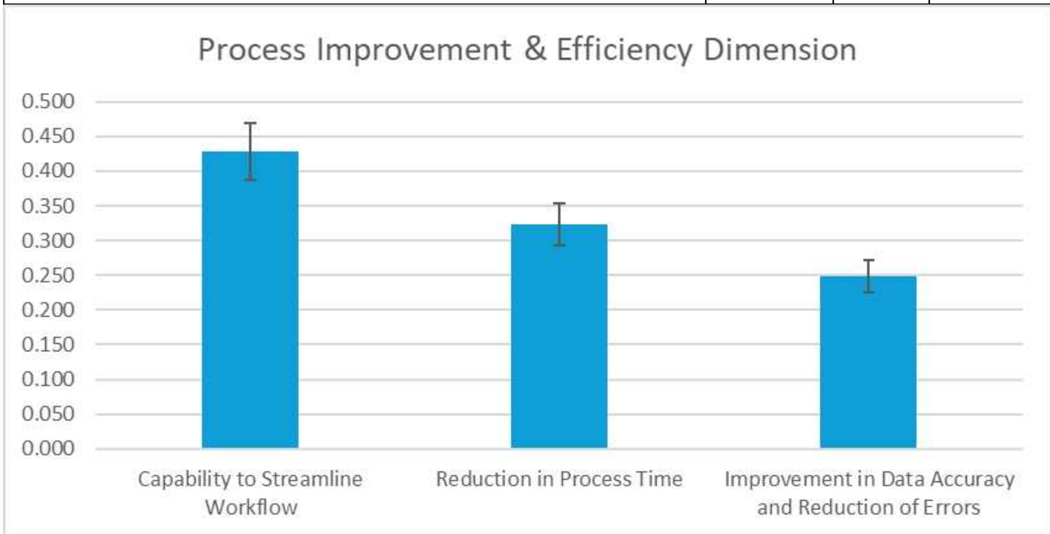

Figure 6. Resulted weights for Process Improvement & Efficiency Dimension

Capability to Streamline Workflow was identified as the most impactful criterion, with a weight of 42.8%, reflecting its importance in improving efficiency within the digitalization of construction processes. The error interval for this criterion does not overlap with the others, solidifying its position as the highest priority.

Reduction in Process Time ranked second, with a weight of 32.3%, showing that time efficiency is also highly valued by the experts. Meanwhile, Improvement in Data Accuracy and Reduction of Errors, with a weight of 24.9%, was ranked third but still holds considerable importance.

The high consensus among the experts and the clear ranking of these criteria demonstrate a strong, unified perspective on what drives success within the Process Improvement & Efficiency dimension.

The analysis of the Technology & Integration dimension revealed a consistency ratio of 9.7%, which is within the acceptable limit of 10%, confirming the reliability of the judgments. In addition, the consensus among the experts was high, reaching 79.2%, indicating a strong agreement in their views on the importance of the criteria.

The following table and graph show the final results for the Technology & Integration dimension:

Technology & Integration Dimension	Weights	+/-	Ranking
Compatibility with existing IT Infrastructure	0,531	0,160	1
Ease of Integration with Current Workflows	0,355	0,107	2
Interoperability with Other Tools and Systems	0,115	0,035	3

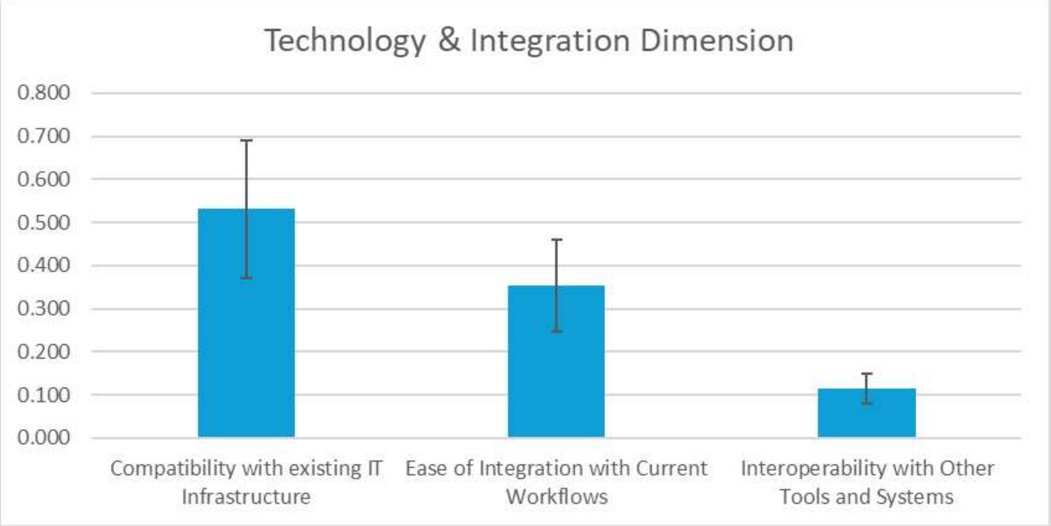

Figure 7. Resulted weights for Technology & Integration Dimension

Compatibility with existing IT infrastructure emerged as the most influential criterion, with a weight of 53.1%. This underlines the critical role of ensuring that new digital tools, such as BIM, can be easily integrated into the existing technological infrastructure of construction projects. Although this criterion has a wider error range than the others, it does not overlap with the others, consolidating its position as the top-ranked factor.

Ease of integration with current workflows, with a weight of 35.5%, ranked second, highlighting the importance of seamlessly integrating BIM tools into existing processes without causing significant disruption.

Interoperability with other tools and systems ranked third, with a lower weight of 11.5%. Although less influential than the other criteria, it remains critical to ensuring that different systems within a project can communicate and work together effectively.

The high level of consensus among the experts and the clear ranking of these criteria reinforces the important role that technology integration plays in the successful adoption and implementation of BIM in construction projects.

Analysis of the Organizational Change Management dimension shows the importance of various factors in supporting the successful implementation of BIM. The consistency rate was 0.3%, which is within acceptable limits, and the consensus among respondents was high (73.8%), indicating a strong agreement on the key factors for success in this area.

The following table and graph summarise the results for the Organizational Change Management dimension:

Organizational Change Management Dimension	Weights	+/-	Ranking
Management Support for BIM Initiatives	0,493	0,026	1
Strategies to overcome resistance to change	0,258	0,014	2
Alignement of BIM Strategy with organizational goals	0,248	0,013	2

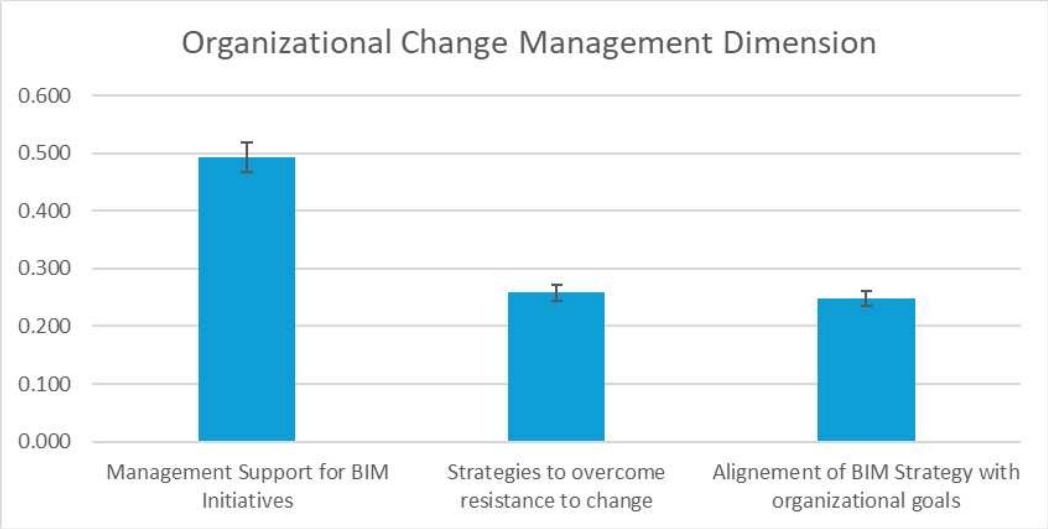

Figure 8. Resulted weights for Organizational Change Management Dimension

Management support for BIM initiatives emerged as the most critical factor, with a weight of 49.3%. This underlines the key role of leadership and management commitment in ensuring the successful adoption and implementation of BIM within organisations. The importance of management support is highlighted by its significantly higher weight compared to the other criteria.

Strategies for overcoming resistance to change and aligning the BIM strategy with the organisation's goals follow closely behind, with weights of 25.8% and 24.8% respectively. Although these two criteria have similar impacts, they are essential in managing change and ensuring that BIM initiatives are aligned with broader organisational goals. Their overlapping weights suggest that both factors are considered equally critical by the experts.

The results highlight the need for strong leadership and well-developed strategies to address resistance to change and ensure that BIM efforts are smoothly integrated into the organisational framework.

The analysis of the Regulatory & Compliance dimension showed a very low consistency ratio of 0.8%, indicating a high level of reliability in the judgments. The consensus among the experts was moderate, with a value of 69.1%, showing a reasonable level of agreement on the importance of the criteria in this dimension.

The following table and graph summarize the final results for the Regulatory & Compliance dimension:

Regulatory & Compliance Dimension	Weights	+/-	Ranking
Ability to adapt to change in legal requirements	0,531	0,046	1
Compliance with industry standards and regulations	0,316	0,027	2
Support for documentation and Audit Trails	0,153	0,013	3

Figure 9. Resulted weights for Regulatory & Compliance Dimension

Ability to adapt to change in legal requirements emerged as the most critical factor, with a weight of 53.1%. This indicates the importance of ensuring flexibility in BIM processes to accommodate evolving legal frameworks, which is vital for the long-term success of digital transformation in construction projects.

Compliance with industry standards and regulations followed, with a weight of 31.6%. This criterion highlights the need to adhere to established guidelines and regulations, ensuring that BIM implementation meets industry benchmarks and maintains regulatory compliance.

Finally, Support for documentation and Audit Trails, with a weight of 15.3%, ranked third. Although this factor is less influential than the others, it remains important for maintaining accurate records and ensuring that audit trails are in place for regulatory purposes.

The high reliability and consensus scores reflect the strong agreement among experts on the significance of regulatory and compliance factors in the successful implementation of BIM.

The User Training & Support dimension displayed excellent consistency, with a consistency ratio of just 0.2%, highlighting the reliability of the results. The consensus level was also strong, with 73.4% agreement among the experts, indicating a solid alignment in their opinions regarding the importance of each criterion.

The table and chart below illustrate the final results for the User Training & Support dimension:

User Training & Support Dimension	Weights	+/-	Ranking
User-Friendliness of the BIM Software	0,529	0,024	1
Availability of Training Resources	0,277	0,013	2
Support and Maintenance Services Provided	0,194	0,009	3

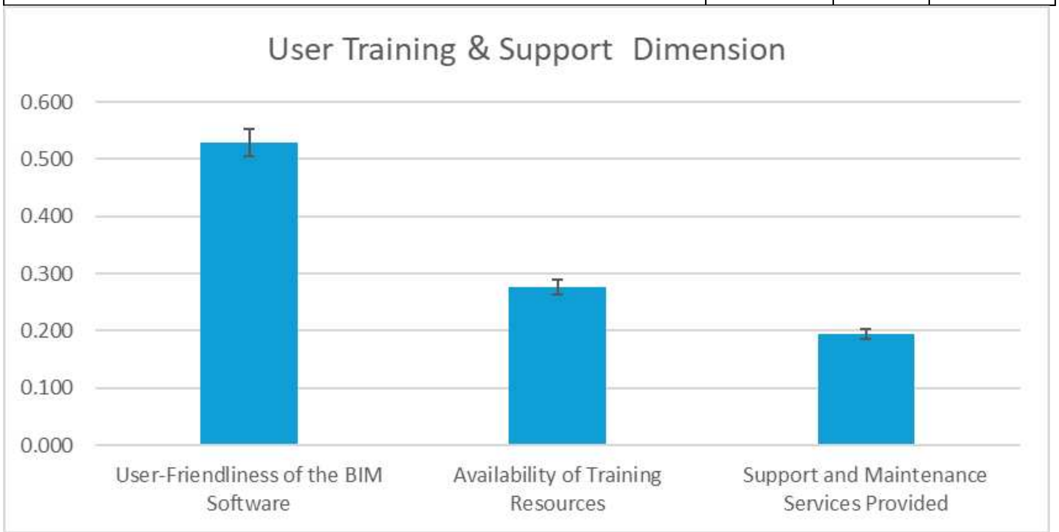

Figure 10. Resulted weights for User Training & Support Dimension

User-Friendliness of the BIM Software ranked as the most important criterion, with a weight of 52.9%. This emphasizes the importance of intuitive, easy-to-use software, which is essential for the successful adoption and use of BIM systems in construction projects.

Availability of Training Resources, with a weight of 27.7%, was ranked second. This reflects the importance of ensuring that users have access to sufficient training resources to improve their skills and proficiency in utilizing BIM tools effectively.

Lastly, Support and Maintenance Services Provided ranked third, with a weight of 19.4%. Although less impactful compared to the other factors, ongoing support and maintenance remain important to ensure that any issues with the BIM software are addressed promptly, thereby improving the user experience.

These findings underline the critical role that both software usability and user support play in the successful implementation of BIM in construction projects.

These detailed figures allow the identification of specific weights and rankings within each success dimension. However, the crucial final step is to calculate the overall weights, which are essential to support the decision-making process in selecting and prioritising projects for portfolio success. To achieve this, the individual weights of each criterion are adjusted based on the priority assigned to their respective Success Dimension, resulting in the final overall weights. The results of this process are presented below:

Success Dimensions		Process Improvement & Efficiency Dimension	0,251		Strategic Value & Alignment	0,259		Technology & Integration
CR	1,60%							
Consensus	37,29%							
Factors			Specific	Overall		Specific	Overall	
		Capability to Streamline Workflow	0,428	0,107	Contribution to strategic objectives	0,404	0,105	Compatibility with existing IT Infrastructure
		Reduction in Process Time	0,323	0,081	Impact on competitive advantage	0,337	0,087	Ease of Integration with Current Workflows
		Improvement in Data Accuracy and Reduction of Errors	0,249	0,062	Long-term value creation	0,259	0,067	Interoperability with Other Tools and Systems
Success Dimensions								
CR		0.9%			9.9%			9.7%
Consensus		79.2%			72.6%			79.2%

Organizational Change Management	0,142		Regulatory & Compliance	0,105		User Training & Support	0,093	
	Specific	Overall		Specific	Overall		Specific	Overall
Management Support for BIM Initiatives	0,493	0,070	Compliance with industry standards and regulations	0,316	0,033	Availability of Training Resources	0,277	0,026
Strategies to overcome resistance to change	0,258	0,037	Ability to adapt to change in legal requirements	0,531	0,056	User-Friendliness of the BIM Software	0,529	0,049
Alignement of BIM Strategy with organizational goals	0,248	0,035	Support for documentation and Audit Trails	0,153	0,016	Support and Maintenance Services Provided	0,194	0,018
0.3%			0.8%			0.2%		
73.8%			69.1%			73.4%		

Figure 11. Calculation of overall weight in AHP hierarchy

From the table above, it is now possible to determine the overall weight given to each criterion and to establish priorities between the dimensions and their specific criteria.

The Process Improvement & Efficiency dimension has a significant weight of 25.1%, with the ability to streamline workflow emerging as the most critical criterion within this dimension. It has a high specific weight of 0.428 and contributes a total weight of 0.107. Reducing process time follows with a total weight of 0.081, while improving data accuracy and reducing errors ranks third with a weight of 0.062. This suggests that streamlining workflows and reducing process time are the key drivers in this dimension.

The Strategic Value & Alignment dimension has the highest overall weight at 25.9%, slightly ahead of Process Improvement & Efficiency. Within this dimension, Contribution to Strategic Objectives is the most important criterion with a specific weight of 0.404, contributing 0.105 to the total. Impact on Competitive Advantage follows closely with a total weight of 0.087, while Long-term Value Creation contributes 0.067. These results underline the importance of aligning projects with strategic goals and ensuring competitive advantage.

In the Technology & Integration dimension, compatibility with existing IT infrastructure dominates with a specific weight of 0.531 and a total contribution of 0.079. The second most important criterion is ease of integration with current workflows with a total weight of 0.053, followed by interoperability with other tools and systems with a contribution of 0.017. This highlights the importance of technological compatibility when integrating BIM into construction projects.

Organisational Change Management ranks slightly lower with a weight of 14.2%. Management support for BIM initiatives is the most influential factor within this dimension, with a total weight of 0.070. Strategies to overcome resistance to change (0.037) and alignment of BIM strategy with organisational goals (0.035) follow closely, indicating the need for strong leadership and well-planned change management to support BIM initiatives.

The Regulatory & Compliance dimension has a total weight of 10.5%. Here, the ability to adapt to changing regulatory requirements has the highest specific weight (0.531) and contributes 0.056 overall. Compliance with industry standards and regulations and support for documentation and audit trails contribute 0.033 and 0.016 respectively. This highlights the critical role of regulatory flexibility and compliance in the success of BIM.

Finally, in the user training and support dimension, BIM software usability stands out with a specific weight of 0.529, contributing 0.049 to the overall score. This is followed by the availability of training resources (0.026) and support and maintenance services provided (0.018), demonstrating the importance of user-centred training and support in ensuring BIM adoption.

Overall, consensus levels vary, with Process Improvement & Efficiency and Technology & Integration showing strong agreement (79.2%), while Strategic Value & Alignment (72.6%) and Organisational Change Management (73.8%) show slightly lower but still moderate consensus. The Regulatory & Compliance dimension has a slightly lower consensus of 69.1%, reflecting some variation in expert opinion in this area.

On the basis of the figures above, the final overall weights for each criterion can now be clearly identified, and priorities can be set across the dimensions and their corresponding specific criteria.

The Process Improvement & Efficiency dimension, and in particular the ability to streamline workflow criterion, tops the ranking with the highest overall weight of 0.107. Close behind, the Strategic Value & Alignment dimension shows its strong influence, with Contribution to Strategic Objectives and Impact on Competitive Advantage securing second and third place with weights of 0.105 and 0.087 respectively.

In fourth place is the reduction in process time, also under the Process Improvement & Efficiency dimension, with a total weight of 0.081, further emphasising the focus on efficiency within the process-related aspects of BIM implementation.

Within the Technology & Integration dimension, compatibility with existing IT infrastructure ranks fifth with a total weight of 0.079, reflecting the importance of technological integration. Similarly, management support for BIM initiatives within the Organisational Change Management dimension ranks sixth with a weight of 0.070, highlighting the critical role of strong leadership in BIM success.

Other notable criteria such as long-term value creation (0.067), improving data accuracy and reducing errors (0.062) and the ability to adapt to changing regulatory requirements (0.056) continue to rank highly, indicating their significant contribution to successful BIM implementation.

At the bottom of the ranking, criteria such as interoperability with other tools and systems (0.017) and support for documentation and audit trails (0.016) represent areas of lower overall importance according to the experts.

The overall weights in the ranking range from 0.107 to 0.016, indicating significant differences in the perceived importance of each criterion. These differences in expert judgement across the different dimensions of success highlight the different levels of priority given to the criteria, and ultimately shape the hierarchy of decision making in the implementation of BIM.

Dimension	Criteria	Overall Weight	Ranking
Process Improvement & Efficiency	Capability to Streamline Workflow	0,107	1
Strategic Value & Alignment	Contribution to strategic objectives	0,105	2
Strategic Value & Alignment	Impact on competitive advantage	0,087	3
Process Improvement & Efficiency	Reduction in Process Time	0,081	4
Technology & Integration	Compatibility with existing IT Infrastructure	0,079	5
Organizational Change Management	Management Support for BIM Initiatives	0,070	6
Strategic Value & Alignment	Long-term value creation	0,067	7
Process Improvement & Efficiency	Improvement in Data Accuracy and Reduction of Errors	0,062	8
Regulatory & Compliance	Ability to adapt to change in legal requirements	0,056	9
Technology & Integration	Ease of Integration with Current Workflows	0,053	10
User Training & Support	User-Friendliness of the BIM Software	0,049	11
Organizational Change Management	Strategies to overcome resistance to change	0,037	12
Organizational Change Management	Alignement of BIM Strategy with organizational goals	0,035	13
Regulatory & Compliance	Compliance with industry standards and regulations	0,033	14
User Training & Support	Availability of Training Resources	0,026	15
User Training & Support	Support and Maintenance Services Provided	0,018	16
Technology & Integration	Interoperability with Other Tools and Systems	0,017	17
Regulatory & Compliance	Support for documentation and Audit Trails	0,016	18

6 Discussion of results

6.1 Reflection on main findings and comparisons

The findings presented in the previous section are the result of research conducted through the collection of 31 expert judgements. These professionals are actively involved in decision-making roles within the construction industry, specifically in areas related to Building Information Modelling (BIM) and digital transformation. Their insights were gathered to assess the critical success factors (CSFs) for the successful implementation of BIM, particularly in the digitalisation of manual processes within construction project management.

The diversity of the experts involved in this study, both in terms of their roles and geographical representation, ensures that the findings reflect a wide range of practical and strategic considerations. Participants came from different sectors of the construction industry and were based in different countries, adding a global dimension to the findings. This diversity in respondents' backgrounds allows the findings to be robust and relevant to a wider range of BIM implementation scenarios.

In addition, the international nature of the participating professionals provides valuable insights into how BIM is being adopted in different regulatory and operational environments. This global perspective is particularly important for understanding the nuances of implementing digital transformation projects in construction, where factors such as local regulations, market maturity and technology readiness can vary significantly.

Process Improvement & Efficiency Dimension

The Process Improvement & Efficiency dimension emerged as one of the most influential factors in the success of BIM implementation within digital transformation projects. With a weight of 25.1%, this dimension highlights the importance of improving workflow processes, reducing project timelines, and ensuring greater data accuracy. By streamlining these core elements of construction management, BIM contributes significantly to overall project success.

One of the most influential criteria within this dimension is the ability to streamline workflow, which received the highest weighting (42.8%). BIM's ability to automate previously manual processes and provide a centralized platform for project coordination is critical to optimizing workflows. Ghaffarianhoseini et al. (2017) support this by highlighting how BIM can improve overall process efficiency by improving data integration across different project phases. Their research shows that BIM not only simplifies communication but also facilitates more efficient decision-making processes, leading to better outcomes. Furthermore, Bortolini (2019) shows that BIM's interoperability with other tools further improves workflow efficiency by minimizing delays caused by miscommunication between different stakeholders.

The reduction in process time is another critical criterion in this dimension, accounting for 32.3% of the total weight. BIM's integration of 4D capabilities (time) allows project managers to visualize the construction schedule, optimize scheduling, and anticipate potential delays. Al Hattab & Hamzeh (2015) highlight the role of BIM in reducing construction timelines by enabling better planning and coordination of resources. Their study highlights that real-time data sharing, enabled by BIM, helps to mitigate delays that may occur due to unforeseen site issues or design conflicts.

This finding is echoed by Abdelalim et al. (2024), who argue that time optimization is one of the most significant benefits of adopting BIM in digital transformation projects, as it directly contributes to reducing overall project costs.

In addition, improving data accuracy and reducing errors, with a weight of 24.9%, underscores BIM's role in improving data integrity. BIM serves as a single source of truth throughout the project lifecycle, ensuring that all stakeholders have access to up-to-date and accurate information. This feature helps to reduce errors and inconsistencies and the integration of lean principles with BIM can further improve accuracy by minimizing waste and errors in construction processes. Similarly, Domingues & Santos (2021) highlight the value of accurate data in minimizing the risk of miscommunication, which is a common problem in traditional project management approaches.

The integration of lean principles with BIM, as discussed by Grilo & Jardim-Goncalves (2010), further enhances efficiency by ensuring that construction processes are not only streamlined but also optimized for resource use. Their research shows that the combination of lean methods with BIM helps to reduce redundancies, improve project flow, and enhance overall process quality—contributing to both time savings and increased project efficiency.

In summary, the Process Improvement & Efficiency dimension clearly demonstrates how BIM contributes to the overall success of construction projects by optimizing workflows, reducing project timescales, and improving data accuracy. These findings are strongly supported by the literature, including studies by Ghaffarianhoseini et al. (2017), Al Hattab & Hamzeh (2015), and Sacks et al. (2010), which highlight the role of BIM in driving efficiency and reducing errors in construction projects. By integrating lean principles and promoting real-time data sharing, BIM serves as a transformative tool to improve the efficiency and effectiveness of digital transformation initiatives in the construction industry.

Strategic Value & Alignment Dimension

The Strategic Value & Alignment dimension plays a key role in the successful implementation of BIM within digital transformation projects, with a significant weight of 25.9%. This dimension reflects the need for organizations to ensure that their BIM initiatives are strategically aligned with broader organizational goals, thereby contributing not only to project-level success but also to long-term value creation and competitive advantage.

Leading the way is the contribution to strategic objectives, which has the highest weighting at 40.4%, highlighting that the true value of BIM lies in its ability to support organizational priorities such as innovation, operational efficiency, and overall growth. Succar (2009) emphasizes that aligning BIM with strategic objectives ensures that it is not just an isolated technological enhancement but a core driver of superior project outcomes that directly advance the organization's mission. BIM's ability to integrate different aspects of a construction project, from design to operations, enables organizations to create a seamless, data-rich environment that aligns with their strategic imperatives and promotes more innovative, efficient, and sustainable business practices.

Equally significant is the impact on competitive advantage, with a weight of 33.7%, highlighting how the adoption of BIM enhances an organization’s market position. According to Rajabi et al. (2022), organizations that strategically adopt BIM are better equipped to reduce costs, improve project delivery times, and enhance service quality, thereby strengthening their competitive position in a highly dynamic market. Chan, Olawumi, & Ho (2019) further suggest that the adoption of BIM allows organizations to differentiate themselves through technological innovation, drive differentiation, and increase their attractiveness to clients by demonstrating more efficient and sophisticated project management capabilities. This competitive advantage is critical for organizations seeking to maintain leadership in the construction industry, especially as clients increasingly demand faster, cheaper, and higher-quality results.

Finally, the long-term value creation criterion, weighted at 25.9%, focuses on BIM's ability to create sustainable value over the entire lifecycle of a building or infrastructure project. Becerik-Gerber et al. (2012) emphasize that BIM's comprehensive digital models provide long-term benefits by improving asset management and reducing costs associated with operations and maintenance. This dimension ensures that BIM is not only valuable during the construction phase but continues to provide returns throughout the project's lifecycle. In addition, Motawa & Almarshad (2013) highlight the integration of advanced technologies with BIM, which can enhance long-term usability by creating robust digital repositories of building information that remain useful for future renovations, upgrades, or maintenance.

In this sense, BIM is becoming a key tool for sustainable business growth, enabling organizations to optimize their assets over time while contributing to environmental sustainability goals. Taken together, these findings underscore the strategic importance of aligning BIM with an organization's long-term goals to ensure that the technology delivers not only immediate project benefits but also lasting competitive advantage and ongoing value creation.

Technology & Integration Dimension

The Technology & Integration dimension emerged as a key factor in the successful implementation of BIM in construction projects, with a significant weight of 15%. This dimension highlights the essential role that technology compatibility, integration, and system interoperability play in ensuring that BIM can be seamlessly integrated into existing workflows and IT infrastructures.

The highest ranked criterion in this dimension is compatibility with existing IT infrastructure, with a weight of 53.1%. This highlights the importance of ensuring that BIM can be smoothly integrated into the organization's existing technological setup—a necessity to reduce the time and cost associated with system upgrades and to avoid potential disruptions. Sacks et al. (2010) highlight the importance of ensuring that BIM tools can operate within an established IT framework, preventing the creation of costly digital silos or incompatibilities that can hinder collaboration and data sharing. Furthermore, Shirowzhan et al. (2020) discuss the critical nature of interoperability in building information modeling, highlighting how the integration of different BIM systems can be hindered if they are not compatible with an organization's existing infrastructure.

The second most critical criterion is ease of integration with current workflows, with a weight of 35.5%. BIM must not only be compatible with the IT infrastructure but also fit seamlessly into the established workflows of project teams. Grilo & Jardim-Goncalves (2010) suggest that ease of integration is essential to encourage greater adoption and minimize user resistance, as it allows BIM to enhance rather than disrupt existing processes. Wu & Tang (2022) further emphasize that integrating BIM into day-to-day operations improves project efficiency and enables teams to better manage complex projects without overhauling their existing workflow systems.

Finally, interoperability with other tools and systems, although weighted lower at 11.5%, remains a critical factor. In an industry where different software platforms are used by various teams and disciplines, ensuring that BIM can communicate effectively with other tools is crucial to fostering collaboration and reducing the risk of data fragmentation. Staub-French & Poirier (2023) note that interoperability is essential to enable multidisciplinary teams to work together effectively, particularly on large construction projects. In addition, Ali et al. (2022) and Grilo & Jardim-Goncalves (2010) stress that the lack of system interoperability can significantly hinder the full potential of BIM, as data exchange between systems is essential for a holistic project view and accurate decision-making throughout the project lifecycle.

Organizational Change Management Dimension

The Organizational Change Management Dimension is essential to the successful implementation of BIM in construction projects, with a significant weight of 14.2%. This dimension addresses the critical need for strong management support and effective change management strategies to ensure the smooth adoption of BIM within an organization.

The most important criterion within this dimension is management support for BIM initiatives, with a significant weight of 49.3%. This reflects the need for senior management to actively support and champion the adoption of BIM. Without visible and committed support from senior management, BIM initiatives are likely to face challenges in securing the necessary resources and achieving alignment with wider organizational goals. Research by Cavka, Staub-French, & Pottinger (2015) highlights that executive support is critical to driving digital transformation and ensuring that BIM is recognized as a strategic priority within the organization. Furthermore, Domingues & Santos (2021) emphasize that strong leadership helps to mitigate resistance to change, a common problem in construction, by fostering a culture that embraces digital innovation.

The second key criterion, strategies to overcome resistance to change, has a weight of 25.8%. Resistance to change is a well-documented barrier to the successful adoption of new technologies such as BIM, particularly in traditionally conservative industries such as construction. MacLoughlin & Hayes (2019) discuss the importance of aligning a change management strategy with the BIM implementation process to minimize employee resistance. This includes clear communication, training, and ongoing engagement with all stakeholders to ensure they understand the benefits of BIM and are equipped for a smooth transition. Additionally, Abu-Moeilak et al. (2023) highlight the value of tailored strategies that address the specific concerns and challenges within an organization, thereby reducing friction during the adoption process.

Finally, aligning BIM strategy with organizational goals is critical, with a weight of 24.8%. Ensuring that BIM initiatives are aligned with the long-term goals of the organization increases the likelihood of their success. Chan, Olawumi, & Ho (2019) highlight that when BIM is aligned with broader organizational strategies, it contributes more effectively to efficiency gains, innovation, and competitiveness. Rajabi et al. (2022) also emphasize that integrating BIM into an organization's strategic framework ensures that it is not treated as a stand-alone technological change but as a core component of the organization's long-term digital transformation goals.

In summary, the Organizational Change Management Dimension highlights the importance of leadership, strategic planning, and overcoming resistance to ensure that BIM is successfully integrated into an organization. Research by Cavka, Staub-French, & Pottinger (2015), MacLoughlin & Hayes (2019), and Chan, Olawumi, & Ho (2019) underscores the need for strong executive commitment and well-executed change management strategies to overcome challenges and align BIM with broader organizational goals. Together, these factors ensure that BIM adoption contributes to sustainable, long-term success in construction projects.

Regulatory & Compliance Dimension

The Regulatory & Compliance dimension, with a weight of 10.5%, is a critical aspect of the successful implementation of BIM in construction projects. This dimension highlights the importance of ensuring that BIM processes and systems are flexible enough to adapt to changes in regulatory frameworks, comply with industry standards, and provide adequate support for documentation and audit trails.

The highest weighted criterion in this dimension is the ability to adapt to changing regulatory requirements, with a significant weight of 53.1%. This criterion highlights the need for BIM systems to be adaptable to the frequently changing legal and regulatory environment in the construction industry. Research by Eastman et al. (2009) highlights how the dynamic nature of construction regulations, particularly across different regions, requires BIM systems to be highly flexible and able to efficiently accommodate these changes. Grilo & Jardim-Goncalves (2010) further support this by illustrating how BIM models in public procurement need to be flexible to adapt to regulatory changes while maintaining accuracy and compliance.

The second key criterion is compliance with industry standards and regulations, with a weight of 31.6%. This criterion ensures that BIM processes comply with established guidelines, ensuring that all project workflows meet the required industry standards. Sacks et al. (2010) discuss the importance of ensuring that BIM systems comply with international and local standards, particularly for projects that span multiple jurisdictions or involve international collaboration. Succar & Kassem (2015) also emphasize that adherence to industry standards is not only a matter of legal compliance but also contributes to smoother project workflows and improved collaboration between teams, which is essential for project success.

Finally, support for documentation and audit trails, although ranked lower with a weight of 15.3%, remains essential for maintaining accurate project records and ensuring accountability. BIM's ability to provide robust documentation and audit trails is critical in supporting regulatory compliance, as well as facilitating future audits and quality assurance processes. Malsane et al. (2015) highlight the importance of BIM-generated audit trails in ensuring transparency and accountability, particularly for large construction projects where thorough documentation is required for both regulatory and internal quality control purposes.

In summary, the Regulatory & Compliance dimension emphasizes the need for flexibility to adapt to changing legal requirements, adherence to industry standards, and robust support for documentation. Together, these factors ensure that BIM processes remain compliant with evolving regulations and contribute to the long-term success of construction projects. Research by Eastman et al. (2009), Sacks et al. (2010), and Grilo & Jardim-Goncalves (2010) supports the critical importance of regulatory and compliance factors in ensuring that BIM not only facilitates project efficiency but also meets the necessary legal and regulatory benchmarks.

User Training & Support Dimension

The User Training & Support dimension, with a weight of 9.3%, plays a critical role in ensuring the successful adoption of BIM in the construction industry. This dimension focuses on equipping users with the necessary skills and providing ongoing support to help them navigate BIM tools effectively. This ensures that users can take full advantage of BIM's capabilities, leading to improved productivity and project outcomes.

The highest ranked criterion in this dimension is the ease of use of BIM software, which carries the most weight at 52.9%. The usability of BIM software is critical to its adoption, as even the most advanced tools can be resisted if users find them difficult to use. Abdirad & Dossick (2016) and Isikdag (2010) highlight the importance of intuitive, user-friendly software in facilitating a smoother transition from traditional processes to BIM-based workflows. Their studies emphasize that the ease with which users can interact with the software has a direct impact on how effectively they integrate BIM into their daily tasks, ultimately affecting the efficiency of project management.

The second criterion, availability of training resources, has a weight of 27.7%. Adequate training resources are essential to ensure that users have the necessary knowledge to use BIM tools effectively. Semaan, Underwood, & Hyde (2021) and Grilo & Jardim-Goncalves (2010) both emphasize the importance of comprehensive training programs in closing the skills gap in the construction industry. Their findings suggest that without sufficient training, users may struggle with the complexities of BIM software, leading to errors and inefficiencies. Therefore, the provision of accessible and well-structured training is critical to fostering a knowledgeable workforce capable of maximizing the potential of BIM.

Finally, the provision of support and maintenance services is weighted at 19.4%. Ongoing support is critical to address any technical issues that may arise during the use of BIM software. Motawa & Almarshad (2013) and Becerik-Gerber et al. (2012) highlight the importance of prompt and reliable support services to ensure the smooth operation of BIM systems. Their research suggests that ongoing technical support is necessary to resolve problems quickly, prevent project delays, and maintain user confidence in the technology.

In conclusion, the User Training & Support Dimension highlights the importance of user-friendly software, sufficient training resources, and reliable support services to ensure the successful adoption of BIM in construction projects. The studies by Abdirad & Dossick (2016), Semaan, Underwood, & Hyde (2021), and Motawa & Almarshad (2013) collectively emphasize that these factors are key to overcoming the challenges associated with BIM adoption, thereby enabling users to fully capitalize on the benefits of digital transformation in the construction industry.

Managerial Considerations for BIM Implementation

More than just a technological upgrade, Building Information Modelling (BIM) is a transformative approach that can significantly improve the efficiency, accuracy, and strategic value of construction projects. However, for organizations to fully realize the benefits of BIM, managers must approach its implementation holistically. When considering the six dimensions identified as critical to BIM adoption, several key considerations emerge: Process Improvement & Efficiency, Strategic Value & Alignment, Technology & Integration, Organizational Change Management, Regulatory & Compliance, and User Training & Support.

At a high level, successful BIM implementation requires strong executive leadership and vision. Executive teams need to recognize BIM as a tool that supports not only operational efficiency but also strategic growth. BIM should be seen as a core component of an organization's broader digital transformation strategy, driving competitive advantage through improved processes, better collaboration, and innovation. To achieve this, top management must fully support BIM initiatives and integrate them into the organization's long-term strategic goals. Cavka, Staub-French, & Pottinger (2015) emphasize the role of executive commitment in aligning BIM adoption with broader organizational objectives.

A key management focus should be on ensuring the seamless integration of BIM into existing workflows and IT infrastructures. This requires a thorough assessment of the organization's current systems and processes to identify areas where BIM can be most effectively applied. BIM's potential to streamline processes, improve data accuracy, and reduce project timescales is well documented, but these benefits can only be realized if the technology integrates smoothly with the organization's existing tools and workflows. Interoperability with other software and systems is also critical, as BIM projects often involve multiple stakeholders working on different platforms. Shirowzhan et al. (2020) highlight the importance of interoperability, while Grilo & Jardim-Goncalves (2010) discuss the necessity of seamless integration to foster cross-disciplinary collaboration.

Resistance to change is another common barrier that managers need to anticipate. Implementing BIM involves a significant change in the way projects are designed, managed, and executed, which can lead to pushback from staff and stakeholders accustomed to traditional methods. To mitigate this, managers should adopt robust change management strategies that emphasize communication, training, and stakeholder engagement. By involving key users early in the implementation process and providing them with the training and resources they need, organizations can foster a culture of innovation and adaptability, reducing resistance and ensuring smoother adoption. MacLoughlin & Hayes (2019) and Abu-Moeilak et al. (2023) stress the importance of change management in overcoming resistance and fostering innovation.

Regulatory and compliance considerations must also be prioritized. Construction projects often span multiple geographies, each with its own regulatory framework and legal requirements. BIM systems must be able to adapt to these variations to ensure compliance throughout the project lifecycle. Managers must ensure that their BIM implementations are flexible and scalable enough to accommodate changes in the regulatory environment and maintain high standards of accountability and documentation, particularly for projects that require rigorous audit trails. Grilo & Jardim-Goncalves (2010) and Malsane et al. (2015) emphasize that BIM's ability to adapt to regulatory changes and maintain comprehensive audit trails is critical for compliance.

Finally, human factors play a critical role in the success of BIM. No matter how advanced or well-integrated the technology, its impact will be limited if the workforce lacks the skills to use it effectively. Managers should ensure that employees receive ongoing training and support. Investing in user training not only maximizes the benefits of the software but also improves overall project outcomes by reducing errors and improving operational efficiency. Semaan, Underwood, & Hyde (2021) and Motawa & Almarshad (2013) highlight the importance of structured training programs and ongoing technical support in overcoming initial learning curves and ensuring the long-term success of BIM.

6.3 Limitations and future research

Despite the valuable insights and practical applications provided by this study, it is important to recognise certain limitations that may affect the generalisability and wider applicability of the findings. A key limitation is the geographical scope of the research, as it is primarily based on data from specific regions. Building regulations, market conditions and levels of BIM adoption can vary significantly between different countries and regions, making it difficult to apply the findings uniformly across the global construction industry. This regional focus may limit the ability to generalise the conclusions to other contexts where regulatory frameworks or industry practices differ significantly. Future studies could broaden their scope by comparing BIM adoption across multiple countries or regions to gain a broader understanding of how regional differences affect implementation.

In addition, the sample size of experts involved in the study, while sufficient to provide qualitative insights, is another limitation. The relatively small number of participants may limit the diversity of views represented, particularly given the reliance on expert judgement during the Analytical Hierarchy Process (AHP) phase. As the AHP method relies heavily on subjective judgements, the limited pool of experts may introduce biases related to their specific organisational background or experience, making the results more reflective of particular contexts rather than the industry as a whole. Expanding future research to include a larger and more diverse group of professionals could provide more balanced results, allowing for a more representative set of criteria and priorities for BIM implementation across different sectors.

Another limitation is the rapid pace of technological advancement in the construction industry. BIM technologies and practices are constantly evolving and the conclusions of this study, while relevant to current practices, may become outdated as new tools, methodologies and innovations emerge. This is particularly true for the advanced dimensions of BIM, such as 5D (cost management), 6D (sustainability) and 7D (facilities management), which are becoming increasingly integral to the digital transformation of the construction industry. To ensure continued relevance, future research could explore the impact of these advanced BIM applications and provide insights into how they contribute to long-term project outcomes, cost savings and sustainability goals.

Furthermore, while this study focuses primarily on the technological and process-oriented aspects of BIM, it may not fully capture the critical influence of human and organisational factors. Elements such as organisational culture, leadership, communication and employee engagement play a significant role in the successful adoption of BIM, yet these areas were not explored in depth. Future research could benefit from examining these softer, non-technical factors to gain a more holistic understanding of the challenges and success factors involved in BIM implementation. In particular, further research into organisational resistance to change could provide valuable insights into the barriers to full BIM integration and how tailored change management strategies can mitigate these challenges.

In addition, the regulatory and compliance landscape is another area that could evolve significantly in the near future. As governments and industry bodies continue to develop and refine BIM-related regulations, future studies should examine how changes in the regulatory framework influence the adoption and implementation of BIM. For example, comparative studies across regions with different regulatory environments could highlight the impact of government mandates or incentives on accelerating BIM adoption in the public and private sectors. This could be particularly useful for policy makers and industry leaders seeking to create a supportive environment for BIM adoption.

In addition, interoperability between BIM systems and other emerging technologies, such as artificial intelligence (AI), the Internet of Things (IoT) and machine learning, is also an important area for future research. As the construction industry increasingly adopts these technologies, the integration of BIM with AI-driven predictive analytics, real-time data from IoT devices, and automation through machine learning could significantly improve project management and decision-making processes. Exploring how these technologies can extend the capabilities of BIM could provide a forward-looking perspective on the future of digital construction.

Finally, this study could serve as a foundation for the development of automated decision-making tools that leverage BIM for project management. Incorporating machine learning algorithms to analyse BIM data and predict project success or optimise resource allocation could be the next frontier of digital transformation in the construction industry. Future research in this area could explore how BIM can be integrated with automated tools to help decision makers select, evaluate and monitor construction projects more effectively.

In summary, while this study provides valuable insights into the critical success factors for BIM implementation, its limitations in terms of geographical scope, sample size and the rapid evolution of technology suggest several avenues for future research. Expanding the scope of the study to include more diverse participants, exploring advanced BIM applications, and integrating emerging technologies such as AI and IoT would not only address current limitations, but also push the boundaries of what BIM can achieve in the construction industry. In addition, future research could delve deeper into human factors and regulatory influences, providing a more comprehensive understanding of the multifaceted challenges and opportunities of the digital transformation of construction.

Conclusions

In conclusion, this study has thoroughly explored the critical success factors (CSFs) for the implementation of Building Information Modelling (BIM) in construction project management, with particular emphasis on the digitisation of manual processes. The research highlights the transformative role of BIM as a tool for integrating different dimensions of construction project management, from design and execution to maintenance and lifecycle management. Through an extensive literature review and the application of the Analytical Hierarchy Process (AHP), the study identified and prioritised a set of key criteria that influence the success of BIM adoption.

The ability of BIM to create long-term value and competitive advantage were highlighted as critical factors in the wider adoption of BIM across the construction industry.

While acknowledging several limitations, including the limited geographical scope and reliance on expert judgement for the AHP process, the study provides a practical framework for organisations seeking to implement BIM. The proposed criteria provide a structured approach for decision makers, helping them to prioritise the factors most relevant to their specific organisational context.

Future research should explore the long-term impact of BIM on sustainability, further investigate the barriers to its full implementation, and examine how emerging technologies such as AI and IoT can be integrated into BIM workflows to enhance its capabilities. Ultimately, this study highlights the strategic importance of BIM in driving digital transformation in the construction industry, positioning it as a critical enabler of efficiency, innovation and sustainability in modern project management.

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