CONSTRUCTION ECONOMICS

DIGITALIZATION IN CONSTRUCITON COST MANAGEMENT

by

SOBHA RANI MK

DISSERTATION

Presented to the Swiss School of Business and Management Geneva

In Partial Fulfillment

Of the Requirements

For the Degree

DOCTOR OF BUSINESS ADMINISTRATION

SWISS SCHOOL OF BUSINESS AND MANAGEMENT GENEVA

January 2025

CONSTRUCTION ECONOMICS

DIGITALIZATION IN CONSTRUCITON COST MANAGEMENT

by

Sobha Rani MK

APPROVED BY

Dissertation chair

RECEIVED/APPROVED BY:

Admissions Director

Dedication

This research is dedicated to the pioneers and visionaries who have tirelessly worked to bridge the gap between traditional construction practices and innovative digital technologies.

To the construction professionals who embrace change and adopt digitalization as a means to improve efficiency, accuracy, and sustainability in cost management, your unwavering commitment inspires progress in our industry..

Finally, to my family, mentors, and colleagues who have supported and guided me throughout this journey, your encouragement and belief in my work have been invaluable. May this research contribute meaningfully to advancing the adoption of digital tools and methodologies in construction cost management, fostering a more efficient, resilient, and sustainable built environment.

Acknowledgements

The completion of this research on digitalization in construction cost management has been made possible through the guidance, support, and encouragement of many individuals and organizations. It is with profound gratitude that I express my appreciation to all those who have contributed to this endeavor.

I extend my heartfelt gratitude to my research mentor, Dr. Ramesh Kumar and the distinguished faculty at SSBM Geneva. Their unwavering support, expert guidance, and deep insights have been pivotal in navigating the intricacies of academic research and refining the quality of this work.

I wish to express my sincere appreciation to the entire team at M/s. Veadik Consulting Solutions Pvt Ltd for their unwavering support and encouragement. Their contributions served as significant motivators throughout the process of undertaking and completing this research.

I extend my deepest gratitude to my family members for their unwavering love, patience, and encouragement throughout this research journey. Their constant support and understanding have been a source of strength, enabling me to overcome challenges and remain focused on achieving my goals. I am truly indebted to their sacrifices, which have made this accomplishment possible.

ABSTRACT

CONSTRUCTION ECONOMICS

DIGITALIZATION IN CONSTRUCITON COST MANAGEMENT

Sobha Rani MK
2024

Dissertation Chair: -------------------

Co-Chair: ----------. Co-Chair’s Name:

This research advances the theoretical understanding of digitalization's role in construction cost management by providing empirical evidence on the comparative advantages of digital tools, such as Building Information Modeling (BIM), over traditional methodologies. By addressing critical gaps in the current literature, the study highlights the practical benefits of digital adoption, offering a robust, data-driven foundation for future research in this domain.

The findings emphasize the transformative impact of digital tools on cost efficiency, project timelines, and operational performance. BIM and other digital technologies streamline processes, reduce errors, and enhance collaboration among stakeholders, delivering measurable improvements in construction project outcomes. As the construction industry faces increasing demands for efficiency, sustainability, and cost optimization, this study highlights the urgent need for widespread digital integration.

Practical implications derived from this research offer clear guidance for multiple stakeholders. Construction firms are urged to prioritize investments in digital tools and workforce training programs to remain competitive and achieve operational excellence. By embracing digitalization, companies can realize significant gains in cost predictability, resource optimization, and overall project success.

For policymakers, this study highlights the importance of fostering a conducive environment for digital transformation. Strategic initiatives, including financial incentives, regulatory frameworks, and supportive infrastructure, are essential to accelerate the adoption of advanced technologies across the construction sector. Policies that facilitate collaboration between public and private entities can further drive innovation and efficiency.

Furthermore, the research highlights the role of academic institutions in bridging the skills gap. By aligning curricula with evolving industry requirements, educational programs can equip future professionals with the technical expertise and practical knowledge necessary to thrive in a digitally advanced construction landscape. Integrating BIM and other digital tools into academic frameworks will ensure that emerging talent is prepared to meet industry challenges.

In conclusion, this study provides a compelling case for digitalization as a critical driver of efficiency and cost management in construction. It offers actionable insights for firms, policymakers, and academia, collectively paving the way for a more innovative and sustainable industry future.

TABLE OF CONTENTS

CHAPTER V: DISCUSSION

CHAPTER VI: SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Introduction

The construction sector, a pivotal element of the global economy, is essential in facilitating infrastructure advancement, generating employment, and promoting economic development. According to the McKinsey Global Institute (2020), the construction sector accounts for approximately 13% of the global Gross Domestic Product (GDP). Despite its economic importance, the industry has consistently been marred by inefficiencies, project delays, and cost overruns. In fact, the productivity of the construction industry has grown by only 1% annually over the past two decades, lagging behind other sectors like manufacturing, where productivity has increased by an average of 3.6% annually (McKinsey, 2017). A key factor contributing to the inefficiencies in the construction sector is the dependence on conventional techniques for project management and financial oversight. Traditionally, construction companies have utilized manual workflows and rudimentary digital tools, such as 2D AutoCAD, for design, drafting, and cost evaluation. While AutoCAD has been a prevalent tool for several decades, its shortcomings, including the disconnection between design and cost information, have increasingly posed challenges for contemporary construction endeavours. This is where BIM offers a solution by integrating design, cost estimation, and scheduling into a single platform, BIM enables real-time collaboration and enhances project efficiency (Eastman et al., 2011). Consequently, construction projects administered through traditional methods frequently experience communication failures, design inaccuracies, and inefficiencies that contribute to budget overruns and delays.

Real estate, infrastructure, and industrial structures all fall under the category of construction, which makes up the largest sector of the global economy and represents 13% of global GDP. (McKinsey, 2020). By 2030, the world's building production would total US$ 15.2 trillion, of which US$ 7.4 trillion would come from the Asia-Pacific region, US$ 2.4 trillion from North America, and US$ 2.5 trillion from Western Europe. Construction will experience higher yearly growth than manufacturing or services between 2010 and

2030, at 3.4% on average. (Oxford Economics, 2021). The approach further increased "construction spending estimated to exceed 13.5% GDP in 2030." There will be a select few nations that will experience the most growth. Only four countries-China, India, the United States, and Indonesia-will account for 58.3% of projected worldwide growth in construction between 2020 and 2030 (Marsh, Guy Carpenter, 2021).

The construction industry plays a significant part in the economy of any country. The construction business uses the most labor, materials, and financial resources; thus, making the best use of them is essential. Construction economics has emerged as a distinct discipline from design and construction, leading to construction cost management roles that guide various economic aspects of building from the project's inception to completion (Construction Economics, 2012).

Government policy places a lot of importance on the construction sector. The acknowledgment of construction's significance to a country's economy is primarily to blame. The construction industry, broadly defined as producers of building materials, tools, and components as well as a variety of professional services offered by architects, surveyors/cost managers, engineers, and property managers, typically represents 15–16% of total annual economic activity (Myers, 2019).

The economics of building projects consider broad customer categories, each client's unique demands, the factors that influence those needs, and the most effective means to satisfy those needs. Examination of the life cycle costs of potential solutions to the issue of requirement fulfilment. (Ofori, 1990).

As per the argument by Hillebrandt "the application of the techniques and skills of economics to the study of the construction firm, the construction process, and the construction industry" is a relatively broad definition of construction economics. (Hillebrandt,1985).

Out of 1579 infrastructure projects, 425 have had cost overruns of more than 4.83 lakh crore, or 22 percent of the initial cost, according to a report by the Indian Ministry of

Statistics and Programme Implementation. (Press Trust of India, 2022) A cost overrun is one element that negatively impacts the construction business and affects the parties to contracts.

Morris (1987) projected that “numerous examples of project overruns from 40% to 200% occurred globally”. 18% of the 60 large engineering projects studied by the IMEC (International Program in the Management of Engineering and Construction) experienced significant cost overruns. (Miller, 1987).

In the construction sector, the most popular systems for preparing quantities, estimating and planning costs, monitoring costs, and managing final accounts are Build-soft and Microsoft Excel. The fundamental issue with these processes is that they are separate from the rest of the project information area. It raises the possibility of errors arising from various sources, including real-time data management between stakeholders and data transfer from accounting systems.

These issues can be minimized to improve project revenues and efficiency with better planning and technological support. Digital technologies can facilitate increased collaboration and data-driven decision-making. The way the construction industry tackles design, operations, and construction, as well as partner relationships, will change due to these advancements. The Internet of Things (IoT) integration with smart buildings and infrastructure will increase data accessibility, more competent support operations, and promote performance-based and collaborative contracting business models. Building Information Modeling (BIM) can assist in the creation of a complete three-dimensional model (a “digital twin”) throughout the design phase and the remainder of the value chain. Adding additional layers, such as cost and schedule, would undoubtedly improve the construction process (McKinsey, 2020).

A significant challenge associated with conventional techniques such as 2D AutoCAD is their failure to facilitate real-time collaboration among the diverse stakeholders engaged in construction initiatives. Construction initiatives generally encompass various entities, including architects, engineers, contractors, subcontractors, and clients, all of whom depend on precise and current project data. Within a traditional workflow, modifications made to the design by one entity may not be promptly reflected in the documents accessible to others. This absence of synchronization among design, cost, and scheduling information can result in expensive mistakes, such as procuring incorrect materials or scheduling labor for tasks that are not yet prepared for execution (Kymmell, 2008). These inefficiencies exacerbate the industry's persistent issues of budget overruns and project delays. Additionally, the conventional approach to cost management within the construction sector is notably fragmented, featuring distinct systems for design, cost estimation, and project scheduling. This fragmentation hinders project managers from acquiring a holistic view of project advancement, resource allocation, and financial limitations. As noted by Kashlev (2008), traditional cost estimation techniques, which often rely on manual computations and spreadsheets, are susceptible to human error and do not deliver the level of granularity necessary for managing extensive, intricate projects. These manual techniques also complicate the tracking of alterations in project scope or design, resulting in recurrent budget adjustments and cost overruns. In response to these challenges, the construction industry is increasingly turning to digital technologies, particularly Building Information Modeling (BIM), to improve project management and cost control. BIM constitutes a digital representation of a building's physical and functional attributes that amalgamates design, cost, scheduling, and resource information into a singular, cohesive model. In contrast to 2D AutoCAD, which offers merely a static, two-dimensional portrayal of a building, BIM enables dynamic, real-time collaboration among all project stakeholders (Azhar, 2011). BIM provides a three-dimensional (3D) model of the building, which can be updated in real-time to reflect changes in design, cost, and scheduling, ensuring that all stakeholders have access to the most current project information.

One of the key advantages of BIM over traditional methods like 2D AutoCAD is its ability to integrate design and cost data. Azhar et al. (2012) found that BIM enables more accurate cost estimation by automating quantity take-offs and linking these quantities directly to the project's budget. In conventional cost management practices, quantity take-offs—the method of determining the amounts of materials necessary for a project—are generally executed manually, which is often labor-intensive and susceptible to inaccuracies. BIM streamlines this procedure by producing quantity takeoffs directly from the three-dimensional model, thereby minimizing the chance of mistakes and ensuring that cost projections are precise and current (Eastman et al., 2011). Such a level of integration between design and cost information is unattainable with traditional 2D AutoCAD systems. Beyond enhancing cost assessments, BIM also improves project scheduling and resource allocation. By associating the 3D model with the project timeline, BIM empowers project managers to visualize the construction process and detect possible scheduling conflicts prior to their occurrence (Hardin & McCool, 2015). This functionality, referred to as 4D BIM, allows project managers to optimize resource distribution and diminish the chances of delays. For instance, should a delay manifest in one segment of the project, the BIM model can be modified to illustrate the repercussions on subsequent tasks, permitting project managers to revise the schedule and reallocate resources as necessary. This capability for real-time project oversight represents a considerable advancement over the static scheduling frameworks employed in traditional approaches (Azhar, 2011).

Moreover, BIM supports collaboration by providing a central platform where all project stakeholders can access and share information in real-time. This collaborative environment reduces the likelihood of miscommunication and ensures that all parties are working from the same set of information (Azhar et al., 2012). In a conventional workflow utilizing 2D AutoCAD, each participant generally works with their individual set of drawings and documents, which can result in inconsistencies and errors when modifications are introduced. With BIM, alterations made to the model by one participant are automatically mirrored in the model available to all stakeholders, ensuring that everyone remains aligned (Hardin & McCool, 2015).

Beyond cost and scheduling improvements, BIM also offers significant advantages in terms of sustainability and lifecycle management. Byun and Sohn (2020) emphasize that

BIM's ability to simulate various building performance scenarios, such as energy consumption and environmental impact, allows for more informed decision-making during the design phase. This capability, known as 6D BIM, enables architects and engineers to design more sustainable buildings by analysing the long-term impacts of different design choices. Additionally, BIM supports facilities management by providing a digital record of the building's components and systems, which can be used for maintenance and operations throughout the building's lifecycle (Azhar, 2011). This level of lifecycle management is not possible with traditional methods like 2D AutoCAD, which focus primarily on the design and construction phases of the project.

The growing adoption of BIM in the construction industry reflects a broader trend toward digitalization. As projects become more complex and demanding, the limitations of traditional methods like 2D AutoCAD are becoming increasingly apparent. While 2D AutoCAD has served the industry well for many years, it is no longer sufficient to meet the demands of modern construction projects. BIM, with its ability to integrate design, cost, scheduling, and sustainability data, offers a more efficient and effective approach to construction project management (Eastman et al., 2011). However, despite its advantages, the widespread adoption of BIM has been slow due to a variety of challenges, including high implementation costs, a lack of skilled professionals, and resistance to change within the industry (Kushwaha, 2016).

Hence, the construction industry's reliance on traditional methods like 2D AutoCAD has contributed to persistent inefficiencies, cost overruns, and delays. The shift toward digital technologies, particularly BIM, represents a significant advancement in addressing these challenges. BIM offers a transformative approach to construction project management by integrating design, cost, scheduling, and sustainability data into a single, unified model. This research explores the impact of digitalization, specifically through BIM, on construction cost management and compares it with traditional methods like 2D AutoCAD, emphasizing how digital tools can improve efficiency, reduce errors, and enhance collaboration across construction projects.

1.2 Research Problem

In the dynamic and ever-changing construction sector, the use of digital technology has become crucial for improving efficiency and effectiveness in different aspects of project management. An essential topic that requires comprehensive examination is the digitization of construction cost management. Although digital tools are increasingly being used in the construction industry, there is still a noticeable lack of understanding regarding the full impact of digitalization on the management of building costs. This study aims to fill this void by examining the difficulties and advantages related to the incorporation of digital technologies in the management of building costs.

The problems faced in the existing cost management professionals includes fragmented process, lack of adequate information, tedious work and time pressure. As per (Lu, Lai and Tse, 2019), the current quality control practices contribute to the division and lack of continuity in the construction industry, which can be reduced by implementing technical and organizational advancements. Quantity surveyors/Cost Managers sometimes do challenge tasks that are typically undervalued by other professions involved in architecture, engineering, and construction.

The research gap in digitalization within construction cost management is the lack of comprehensive investigation into integrated and scalable digital solutions that effectively address the complexities of project cost management. This research to focus on real-time data analytics, interoperability, and the overall influence on project performance and financial outcomes.

The current problems faced in the construction cost management are :

Inadequate cost management process: Insufficient cost management procedures in the construction industry frequently result in difficulties in maintaining budget control and the financial well-being of projects. This might occur due to the use of manual, paper-based systems that do not possess the necessary capacity to manage the intricacies of contemporary building projects.

Accuracy in quantity take off : Precision in quantity estimation is essential for calculating material expenses, and relying on manual or unreliable techniques might result in budget inconsistencies. Conventional techniques, such as physical measurement or 2D drawings, might not effectively reflect the complexities of 3D project components.

Fastness: The efficiency of cost management processes is crucial for making timely decisions. Delays in acquiring cost information might occur due to manual or delayed processes, impeding the capacity to promptly address changes in project scope or unforeseen challenges.

Coordination with multiple stake holders for decision making: Construction projects necessitate the involvement of various stakeholders, and efficient coordination among them is crucial for decision-making. Inadequate communication and collaboration can result in delays in obtaining approvals, implementing modifications, or resolving issues, so affecting project schedules and expenses.

1.3 Purpose of Research

The purpose of this research is to explore the transformative potential of digitalization, particularly Building Information Modeling (BIM), in revolutionizing construction cost management practices. It aims to investigate how advanced digital tools can address the limitations of traditional methods, such as inefficiencies, inaccuracies, and communication gaps, while enhancing overall project outcomes. The research seeks to provide a comprehensive understanding of the role of digital tools in streamlining processes like quantity take-offs, cost estimation, and stakeholder coordination. By focusing on the practical application of standards like the AEC (UK) BIM Standard for Revit and BS 1192, the study intends to evaluate the effectiveness, satisfaction, and efficiency associated with digitalization in construction cost management. Additionally, the research aims to identify and address the barriers to digital adoption, such as skill gaps, high implementation costs, and resistance to change, particularly for small and medium-sized enterprises (SMEs). Through quantitative and qualitative analyses, this study aspires to offer actionable insights and strategies for fostering the adoption of digital tools in the construction industry. Ultimately, the purpose of this research is to contribute to the advancement of cost-efficient, collaborative, and sustainable practices in the construction sector, paving the way for improved decision-making, real-time project management, and alignment with global digital transformation trends.

1.4 Significance of the Study

The significance of this research lies in its potential to address critical challenges in the construction industry by advancing digital transformation in cost management practices. The construction sector, often characterized by inefficiencies, cost overruns, and communication breakdowns, is undergoing a paradigm shift with the adoption of digital tools like Building Information Modeling (BIM). This study contributes to the growing body of knowledge by offering empirical evidence and practical insights into the effectiveness of digital tools in overcoming traditional inefficiencies and enhancing project outcomes.

By focusing on the Indian construction industry, the research highlights region-specific challenges, such as the prevalence of manual methods, resistance to technological change, and skill shortages, while offering globally relevant insights into best practices. It evaluates how digital tools streamline processes such as quantity take-offs, cost estimation, and real-time collaboration, providing a framework for improved project planning and execution. Additionally, the research underscores the economic and operational benefits of adopting standards like the AEC (UK) BIM Standard and BS 1192, setting a benchmark for structured implementation.

This study is significant for various stakeholders, including policymakers, construction firms, and technology providers. For policymakers, the findings provide evidence to formulate supportive policies and frameworks to encourage digital adoption across the industry. For construction firms, particularly small and medium-sized enterprises (SMEs), the research offers strategies to overcome barriers such as high implementation costs and skill gaps. Technology providers can benefit by understanding user challenges and requirements, enabling them to tailor solutions for greater accessibility and impact.

Moreover, the study contributes to the broader goal of sustainable development by promoting cost-efficient and resource-conscious practices. The integration of BIM with advanced tools not only improves accuracy and efficiency but also reduces waste, aligning with environmental and economic sustainability goals. Ultimately, this research plays a pivotal role in fostering innovation, collaboration, and competitiveness in the construction sector, ensuring its alignment with global digital transformation trends.

1.5 Research Purpose and Questions

The primary purpose of this research is to explore the transformative potential of digitalization in construction cost management, with a focus on enhancing efficiency, accuracy, and stakeholder collaboration. By evaluating the role of digital tools such as Building Information Modeling (BIM) and other emerging technologies, this study aims to address long-standing challenges in the construction industry, including cost overruns, inefficiencies, and miscommunication among stakeholders. The research seeks to provide actionable insights into how these tools can be effectively implemented to streamline processes like quantity take-offs, cost estimation, and real-time project updates. It also aims to identify barriers to digital adoption, such as resistance to change, lack of skills, and high implementation costs, and propose strategies to overcome these obstacles. Ultimately, this study intends to contribute to the knowledge base for industry professionals, policymakers, and technology providers by demonstrating the benefits of digitalization in achieving cost-efficient, sustainable, and collaborative construction practices.

- How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence user perceptions of accuracy and time-saving in construction cost management processes?
- What is the relationship between the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) and its perceived effectiveness in tracking cost variations in construction projects?
- How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence user satisfaction levels in construction cost management?

- What is the relationship between the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) and the perceived effectiveness of providing real-time project cost updates in construction cost management?
- How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence the frequency of miscommunication among stakeholders in construction cost management?
- How does the proficiency level of comprehensive BIM tools compare to hybrid tool approaches in terms of enhancing user performance and satisfaction in construction cost management?
- How does the use of 3D modeling compare to 2D methods in terms of efficiency and time savings for quantity takeoff processes in construction cost management?
- What is the impact of accuracy in time-saving, cost variation tracking, real-time project cost updates, and stakeholder miscommunication on user satisfaction with cost management tools in the construction industry?

These questions aim to provide a comprehensive understanding of the opportunities and challenges associated with digitalization in construction cost management and pave the way for practical recommendations to drive industry-wide adoption.

1.6 Background of the Study

The construction industry is a vital pillar of the global economy, driving infrastructure development, job creation, and overall economic progress. As projected by Oxford Economics (2021), the global construction industry is expected to grow at an annual rate of 3.4% between 2010 and 2030, a growth rate that outpaces both the manufacturing and services sectors. This forecasted expansion is due to the increasing demand for large-scale infrastructure projects, urban development, and technological advancements in construction methods. However, with this growth comes the heightened complexity of projects, which has highlighted the limitations of traditional project management and cost control methods, particularly when managing large, dynamic construction environments.

Historically, construction cost management has relied on manual processes, spreadsheets, and digital drafting tools like 2D AutoCAD. These methods have been effective in the past, but as the scale of construction projects has grown, they have proven inadequate. Vitásek and Matějka (2017) argue that traditional methods are fragmented, with design, cost estimation, and scheduling often handled separately, leading to inefficiencies, miscommunication, and an increased likelihood of errors. Manual cost estimation processes are not only time-consuming but also prone to inaccuracies, often resulting in cost overruns and project delays.

As the complexity of construction projects has increased, so too has the need for more advanced and integrated project management tools. Building Information Modeling (BIM) has emerged as a response to the industry's inefficiencies, offering a digital platform that integrates design, cost estimation, scheduling, and resource management into a single cohesive model. BIM allows for real-time updates and collaboration, providing project managers with a comprehensive view of the project at every stage. This level of integration makes it easier to manage costs and schedules while reducing the risk of errors and delays (Azhar et al., 2012).

One of the key advantages of BIM is its ability to automate traditionally manual processes such as quantity takeoffs and cost estimation. By generating these takeoffs directly from 3D models, BIM reduces the time and labor involved in cost estimation while improving accuracy. This automation ensures that cost estimates are based on real-time data, which is essential for managing large, complex projects. Kocakaya et al. (2019) demonstrated that projects utilizing BIM experience fewer delays and cost overruns compared to those using traditional methods, primarily due to BIM’s ability to keep stakeholders informed and aligned throughout the project.

BIM also offers significant improvements in collaboration and communication. Traditional methods of construction management often involve silos, where different teams—architects, engineers, contractors—work independently, leading to potential miscommunication. With BIM, all stakeholders can access the same model, enabling real-time updates and ensuring that everyone is working with the most current information. This ability to centralize and share data helps prevent miscommunication and reduces the likelihood of costly errors and delays (Azhar et al., 2012).

However, despite its clear benefits, the adoption of BIM and other digital tools has been slower than expected. Kushwaha (2016) identified several barriers to adoption, including high implementation costs, a lack of skilled professionals trained in BIM technology, and resistance to change from industry stakeholders accustomed to traditional methods. Smaller firms, in particular, face challenges in justifying the upfront costs of adopting BIM. Moreover, the steep learning curve associated with BIM technology can further hinder its widespread adoption.

Another significant barrier is the skills gap in the construction industry. Azhar (2011) points out that many construction professionals lack the technical expertise required to fully utilize BIM's capabilities. As a result, even in cases where BIM offers clear advantages over traditional methods, many firms continue to rely on manual processes and outdated tools. Addressing this skills gap through training and education programs is critical to increasing BIM adoption and ensuring that the industry can fully leverage the benefits of digitalization.

In response to these challenges, this research aims to explore the impact of BIM and other digital tools on construction cost management, particularly in terms of efficiency, error reduction, and collaboration enhancement. The research will also identify the barriers to BIM adoption and propose strategies for overcoming these challenges, providing valuable insights into the future of construction project management and the broader implications of digitalization in the industry.

1.7. Conversion of 2D Drawings to 3D Building Information Models (BIM)

The transformation of 2D design documentation into detailed 3D Building Information Models (BIM) using Autodesk Revit represents a fundamental shift in modern construction and architectural practices. This process involves converting manual or computer-aided designs (CAD) into intelligent 3D models, enabling enhanced visualization, planning, and project execution. This case study delves into the methodologies, benefits, challenges, and best practices associated with this digital transition, with a focus on the insights provided by leading researchers and practitioners in the field.

Building Information Modeling (BIM)

Building Information Modeling is a transformative, intelligent 3D model-based process that empowers architecture, engineering, and construction (AEC) professionals to efficiently plan, design, construct, and manage buildings and infrastructure. As Lyu et al. (2020) describe, BIM integrates multidisciplinary data into a single model, facilitating real-time collaboration and decision-making throughout a project’s lifecycle. With its parametric design capabilities and integration of various building systems, BIM has become a cornerstone of modern construction management.

Manual Drafting

Manual drafting represents the traditional method of creating technical drawings by hand. Siminialayi, Leticia Iyarubo, and Fomsi, Esther Fabiawari (2023) define manual drafting as the use of physical tools such as pencils, rulers, compasses, and protractors to produce design documentation. Although this approach laid the foundation for architectural and engineering drawings, it is inherently time-intensive, prone to errors, and lacks the collaborative capabilities offered by digital solutions. The limitations of manual drafting have driven the widespread adoption of digital tools in the AEC industry.

1.8. Computer-Aided Design (CAD)

Overview of CAD

Computer-Aided Design (CAD) revolutionized the field of design by introducing computers as tools for creating, modifying, analyzing, and optimizing designs. As noted by the "CAD Software" (1984) report, CAD enhances productivity, improves design quality, and facilitates documentation and database creation. CAD output often takes the form of electronic files that can be used for printing, machining, or other manufacturing operations. It also provides the basis for innovations like patent application designs and electronic design automation (EDA) in electronic systems.

Historical Development of CAD

The origins of CAD can be traced back to Ivan Sutherland and David Evans at MIT, who developed the groundbreaking "Sketchpad" program in 1963 (Rolph, 1982). This pioneering effort laid the groundwork for modern CAD systems, transforming design and engineering processes.

Prominent CAD Software

Farrimond et al. (2007) outline several well-known CAD software tools, each tailored for specific industries:

AutoCAD: Widely used in architecture, engineering, and construction, AutoCAD offers 2D and 3D drafting capabilities and parametric modeling.

SolidWorks: Primarily used in mechanical engineering, SolidWorks features simulation and parametric design tools.

CATIA: Common in aerospace and automotive industries, CATIA provides advanced surface modeling and parametric design.

Revit: Tailored for AEC professionals, Revit emphasizes Building Information Modeling with parametric design features.

Fusion 360: Ideal for product design, Fusion 360 integrates cloud collaboration and computer-aided manufacturing (CAM).

Rhino: Known for its advanced surface modeling and NURBS-based design, Rhino is used in industrial and architectural applications.

AutoCAD Civil 3D: Specially designed for civil engineering, this tool includes BIM capabilities for infrastructure design.

Inventor: Focused on product design, Inventor supports parametric modeling and simulation.

SketchUp: Known for its intuitive 3D modeling capabilities, SketchUp is popular among architects and interior designers.

MicroStation: Commonly used in infrastructure projects, MicroStation provides robust BIM features.

AutoCAD LT: A streamlined version of AutoCAD focused on 2D drafting.

Building Information Modeling (BIM) vs. CAD

While CAD serves as a foundational tool for digital drafting, BIM expands on its capabilities by integrating multidisciplinary data into intelligent 3D models. BIM's parametric design and real-time collaboration features provide insights beyond visualization, enabling project teams to optimize design decisions, track progress, and manage costs throughout a building's lifecycle. As highlighted by Koubaa and Qureshi (2018), cloud collaboration in BIM allows project teams to work seamlessly across geographies by leveraging internet-based platforms. This approach facilitates real-time data sharing, document management, and collaborative design processes. Cloud-enabled BIM ensures that stakeholders can access the latest project data, reducing delays and improving decision-making efficiency. The conversion of 2D drawings to 3D BIM models using tools like Autodesk Revit represents a pivotal advancement in the AEC industry. By transitioning from manual and CAD drafting to intelligent BIM workflows, professionals can achieve higher accuracy, efficiency, and collaboration.

1.9 The Evolution of Construction Cost Management

Construction cost management has undergone significant changes over the decades, transitioning from rudimentary, manual methods to more advanced, technology-driven systems. In the early stages of the industry, cost management relied heavily on manual processes such as paper-based cost estimation, bookkeeping, and physical calculations. These methods, while functional for smaller projects, lacked the precision and efficiency necessary for managing large-scale construction projects. As projects grew in complexity and size, the limitations of these manual approaches became increasingly evident. Kashlev (2008) pointed out that the lack of real-time data and integration across different project phases often led to miscommunication, budget overruns, and delays.

In the 20th century, the introduction of 2D CAD (Computer-Aided Design) systems, such as AutoCAD, brought significant improvements to the industry. AutoCAD allowed architects and engineers to create digital designs and drafts, replacing the time-consuming manual drafting process. However, despite its efficiency in design, 2D AutoCAD remained primarily focused on two-dimensional representations of buildings, providing no capability for integrating cost or scheduling data. As a result, cost management processes remained largely manual, with quantity takeoffs and budget estimations requiring separate tools, often relying on spreadsheets and manual inputs. Vitásek and Matějka (2017) highlighted that the lack of integration between design, cost estimation, and project scheduling remained a significant obstacle, particularly for larger, more complex projects.

One of the major shortcomings of 2D CAD systems is the absence of real-time collaboration. When changes are made to the design, these changes do not automatically reflect in the cost estimates or project schedules, which can lead to miscommunication and costly errors. For instance, if the design is modified late in the project, the cost estimations must be manually recalculated, a process that can introduce delays and errors. This fragmented approach, with disconnected systems for design, cost management, and scheduling, limited the construction industry’s ability to manage large projects efficiently.

As construction projects became more complex and required greater precision, the need for an integrated approach to cost management became increasingly clear. The introduction of Building Information Modeling (BIM) marked a significant advancement in addressing these inefficiencies. Unlike traditional systems, BIM allows for the integration of design, cost, scheduling, and resource management into a single platform, enabling real-time collaboration among all stakeholders. Azhar et al. (2012) noted that BIM's ability to provide accurate, real-time data across all aspects of the project dramatically reduces the likelihood of errors and delays.

BIM’s introduction to the construction industry represented a shift from reactive to proactive cost management. Rather than relying on post-design cost estimation and manual recalculations when changes occur, BIM integrates cost estimation into the design process itself. This integration ensures that any design changes made during the project are automatically reflected in the cost estimates, allowing project managers to adjust budgets and resources in real time. This level of integration and real-time updating was a crucial step forward, making BIM an essential tool for managing costs in modern construction projects.

Additionally, the use of automation in BIM has revolutionized quantity takeoffs and cost estimation. Traditionally, quantity takeoffs were performed manually, requiring project managers to calculate the materials needed for each phase of the project based on 2D drawings. This process was not only time-consuming but also prone to human error. BIM automates this process by generating quantity takeoffs directly from the 3D model, ensuring that material estimates are accurate and reflect the most current design. This automation has led to significant time savings and improved the accuracy of cost estimations, helping to reduce budget overruns and improve project efficiency (Eastman et al., 2011).

The shift towards BIM represents not only an evolution in cost management but also a broader move toward digitalization in construction economics. As Byun and Sohn (2020) point out, BIM enables project managers to make data-driven decisions, allowing them to predict costs more accurately, optimize resource allocation, and avoid the delays and overruns that have long plagued the industry.

In summary, the evolution of construction cost management has progressed from manual, fragmented processes to the integrated, automated systems offered by BIM. This transformation has not only improved the accuracy and efficiency of cost management but also enhanced collaboration among stakeholders, making it a key component of modern construction project management. The adoption of BIM signals a shift towards proactive, data-driven project management, allowing construction firms to deliver projects on time and within budget.

Levels of BIM (Maturity levels):

Building Information Modeling (BIM) evolves across different maturity levels, with each level representing an incremental step in the adoption and integration of digital technologies within construction workflows. These levels, as described by Jo et al.

(2016), illustrate the progression from basic digital drawings to fully integrated and intelligent models, providing a framework for understanding the extent of BIM implementation in a project.

Level 0 BIM:

At this level, BIM is non-existent. The focus is solely on 2D drawings, which are created using traditional methods or basic CAD tools. There is no integration or intelligence within the designs, and collaboration is minimal.

Level 1 BIM:

This level involves a combination of 2D drawings and 3D models. While 3D models are used primarily as design and visualization tools, they lack embedded intelligence and are not extensively integrated into the project's lifecycle. Collaboration remains limited, with each stakeholder primarily relying on separate files for their contributions.

Level 2 BIM:

At this stage, each project participant develops their own intelligent BIM models. However, these models are not centrally integrated, meaning stakeholders work independently with limited data sharing. While these models contain intelligence, such as embedded parameters and metadata, collaboration is still not seamless.

Level 3 BIM:

This is the most advanced stage of BIM maturity, where a central, fully integrated BIM model is used. Contributions from all stakeholders are combined into a unified model, enabling seamless collaboration, enhanced accuracy, and efficient data exchange. This level represents true interoperability and supports advanced capabilities like lifecycle management and real-time collaboration.

1.10. Quantity take off:

Quantity Takeoff (QTO) is an essential process in construction, used to calculate the quantities of materials, labor, and resources needed for a project. The integration of Quantity Takeoff within Building Information Modeling (BIM) has revolutionized this process by enhancing accuracy, efficiency, and collaboration. This section outlines the detailed steps involved in performing a quantity takeoff in a BIM model and examines how this approach improves project planning and execution.

1.10.1. Advantages of Quantity Takeoff in BIM:

Enhanced Accuracy and Precision: BIM-based quantity takeoff improves accuracy by extracting precise quantities directly from the model, reducing the potential for human errors typically associated with manual takeoff methods. The model's data-driven approach ensures that measurements reflect real-world dimensions and material properties, leading to more reliable results.

Real-Time Updates and Automation: A key advantage of BIM is its ability to update quantities in real time as changes are made to the design. Any modifications to the model—whether in geometry, materials, or construction sequencing—are automatically reflected in the quantity schedules, ensuring that project teams always have access to the most up-to-date information.

Time Efficiency: Traditional quantity takeoff methods are often time-consuming and labor-intensive. By automating the process through BIM, construction teams can significantly reduce the time spent on takeoff activities, allowing for quicker project planning and cost estimation. This improved efficiency translates into faster decision-making and project execution.

Improved Collaboration and Coordination: The use of BIM for quantity takeoff fosters collaboration among project stakeholders. Since all quantities are derived from a single, shared model, there is less room for miscommunication or conflicting data. This shared platform enhances coordination between design, engineering, and construction teams, ensuring that all parties work with the same set of accurate, consistent information.

Integration with Cost Estimation and Procurement: BIM-based quantity takeoff can be seamlessly integrated with cost estimation and procurement workflows. By directly exporting quantities to cost estimation software, project teams can develop detailed cost breakdowns and procurement strategies that align with the project schedule and budget. This integration ensures that material orders and resource planning are optimized to meet project demands.

Visualization and Validation of Quantities: One of the unique advantages of BIM is the ability to visually validate quantities within the model. Stakeholders can interact with the 3D model to confirm that the quantities extracted align with the actual design, providing an additional layer of verification and minimizing the potential for discrepancies.

Reduction in Material Waste and Resource Optimization: Accurate quantity takeoff ensures that the correct amounts of materials are ordered, reducing the risk of over-ordering or under-ordering. This not only contributes to cost savings but also supports sustainability efforts by minimizing material waste and optimizing the use of resources.

The integration of quantity takeoff within a BIM model offers numerous advantages that enhance project efficiency, accuracy, and collaboration. By following a structured process—from model preparation to the export and review of quantities—construction teams can achieve more reliable takeoff results, contributing to better cost control, resource management, and overall project success. As the construction industry continues to adopt digital methodologies, BIM-based quantity takeoff is becoming an indispensable tool for achieving greater accuracy and efficiency in project planning and execution.

1.11. Visualisation and clash detection

The visualization of Building Information Modeling (BIM) models has emerged as a critical component in modern construction practices, offering significant advantages in project planning, execution, and management. By enabling a comprehensive, data-driven visual representation of building designs, construction professionals can better anticipate challenges, optimize workflows, and facilitate informed decision-making. This paper explores the role of BIM visualization in construction and the strategic benefits it provides to industry stakeholders.

The integration of visualization and clash detection within Building Information Modeling (BIM) plays a pivotal role in modern construction practices by improving collaboration, minimizing errors, and ensuring project accuracy. These two aspects allow stakeholders to virtually simulate and assess various elements of a construction project, offering a proactive approach to identifying potential issues before they arise on-site.

1.11.1 Visualization in BIM:

Visualization in BIM refers to the ability to create and interact with 3D models that represent the physical and functional aspects of a construction project. Through detailed and immersive visual models, stakeholders—such as architects, engineers, contractors, and clients—can gain a comprehensive understanding of the project design and how different systems will interact within the space.

1.11.2. Strategic Advantages

Enhanced Comprehension of Complex Designs: One of the primary advantages of BIM visualization is its ability to transform complex architectural and engineering designs into comprehensible 3D models. Unlike traditional 2D drawings, these models allow stakeholders to visually engage with all aspects of the project, including structural, mechanical, electrical, and plumbing systems. This enhanced understanding is crucial for aligning project objectives and reducing design ambiguities.

Facilitation of Multi-Disciplinary Collaboration: BIM visualization acts as a collaborative platform that integrates inputs from architects, engineers, contractors, and owners. By providing a shared visual model, BIM enhances coordination between different disciplines, fostering a collaborative environment where all parties can work towards a common goal. This integration minimizes communication barriers and promotes a more efficient exchange of information, reducing the likelihood of errors or misinterpretations during project execution.

Proactive Identification of Clashes and Conflicts: The ability to conduct visual clash detection is a significant advantage of BIM models. By simulating the physical and functional components of a building in a virtual environment, project teams can identify potential clashes between various systems—such as mechanical, electrical, and plumbing—before they manifest on-site. This proactive identification of conflicts helps in mitigating risks, reducing costly rework, and minimizing project delays, ultimately leading to more efficient construction processes.

Real-Time Model Updates and Decision Support: BIM visualization allows for real-time updates to the project model, ensuring that all stakeholders have access to the most current information. This dynamic capability supports informed decision-making throughout the project lifecycle, as changes can be visualized instantly, and their impacts on cost, schedule, and resources can be assessed promptly. The ability to simulate different scenarios further enhances strategic planning and project control.

Optimization of Time and Cost Management: The visualization of BIM models contributes significantly to the optimization of time and cost management in construction projects. Through precise visual representation, project teams can analyze construction sequences, optimize workflows, and plan resource allocation more effectively. The ability to visualize material quantities and construction phases in a detailed manner aids in more accurate cost estimation and budget control, contributing to overall project efficiency.

Enhanced Client Communication and Stakeholder Engagement: For clients and non-technical stakeholders, visualizing the BIM model provides a clear and intuitive understanding of the project's design intent and progress. This capability facilitates meaningful engagement, enabling clients to provide timely feedback and participate in decision-making processes. Moreover, it helps align client expectations with the final project outcome, reducing the need for revisions and enhancing overall satisfaction.

Improved Safety and Risk Management: BIM visualization extends its benefits to safety planning by allowing construction teams to simulate site conditions, workflows, and potential hazards before construction begins. This proactive approach to safety enables the development of detailed safety protocols and risk mitigation strategies, reducing the likelihood of on-site accidents and ensuring compliance with health and safety regulations.

The strategic use of BIM model visualization in construction offers a multitude of advantages that extend beyond the traditional scope of design representation. By improving interdisciplinary collaboration, enhancing decision-making, optimizing project costs and timelines, and mitigating risks, BIM visualization serves as a pivotal tool in driving project success. Its role in fostering informed engagement among all stakeholders makes it indispensable for modern construction practices, leading to improved project outcomes, increased efficiency, and higher stakeholder satisfaction.

1.12. Clash Detection in BIM:

Clash detection is the process of identifying conflicts or "clashes" between different building systems—such as structural, mechanical, electrical, and plumbing (MEP) systems—within the BIM model. These clashes can occur when two or more components are improperly designed to occupy the same space or interfere with each other's function.

As outlined earlier, BIM's clash detection capabilities are essential for identifying potential conflicts between different building systems. Effective coordination between stakeholders ensures that these clashes are resolved promptly, minimizing delays and avoiding costly rework during the construction phase. Regular coordination meetings supported by the BIM model help teams proactively address these issues.

Example: Weekly coordination meetings between architect, project managers and contractors help to review clashes identified by the BIM software, allowing for swift resolution before construction begins.

1.12.1 Types of Clashes:

Hard Clash: Occurs when two physical elements in the model occupy the same space (e.g., a duct passing through a beam).

Soft Clash: Happens when elements violate spatial or clearance requirements (e.g., insufficient clearance for maintenance or safety regulations).

Workflow Clash: Relates to scheduling conflicts or construction sequencing issues, where elements or tasks interfere with one another during project execution.

1.12.2. Steps in Clash Detection:

Model Integration: The first step involves integrating the different models from various disciplines (e.g., architectural, structural, and MEP) into a single BIM model. Tools like Navisworks, Solibri, or Revit are used for this purpose.

Automated Clash Detection: BIM software automatically identifies potential clashes by analyzing spatial and functional interactions between building systems. The software provides a visual and data-driven report of all detected clashes.

Clash Review and Resolution: Once clashes are identified, project teams review each conflict to determine its severity and impact on construction. Based on the analysis, teams collaborate to resolve these issues by adjusting designs, re-routing systems, or revising materials.

Documentation and Reporting: The BIM software generates a comprehensive clash report, which documents the identified conflicts, their locations, and the proposed resolutions. This report is then shared with all project stakeholders for transparency and further action.

1.12.3. Advantages of Clash Detection:

Reduced Rework and Costs: Identifying and resolving clashes in the BIM model before construction starts significantly reduces the risk of rework on-site, saving both time and cost. Early detection prevents delays caused by system conflicts that would otherwise need to be fixed during construction.

Improved Project Coordination: Clash detection enhances coordination between different teams (architects, engineers, contractors), ensuring that designs from various disciplines work harmoniously. This leads to a more integrated and collaborative approach to construction.

Enhanced Risk Management: Proactively addressing clashes minimizes the risk of unforeseen issues arising during construction, leading to smoother project execution. It also ensures compliance with safety and regulatory standards, reducing the likelihood of future legal or operational risks.

Optimized Construction Sequences: Clash detection aids in identifying workflow clashes, allowing project teams to adjust construction schedules and optimize sequences for efficiency. This reduces the likelihood of delays caused by task interferences or misaligned activities.

The combination of visualization and clash detection in BIM significantly enhances the efficiency and accuracy of construction projects. By visualizing the project in a virtual environment, stakeholders can better understand and optimize designs, while clash detection ensures that potential conflicts are addressed before they escalate into costly issues. Together, these processes contribute to improved collaboration, minimized risks, and successful project delivery, making them integral to modern construction practices.

1.12.4. Strategic Advantages

Enhanced Comprehension of Complex Designs: One of the primary advantages of BIM visualization is its ability to transform complex architectural and engineering designs into comprehensible 3D models. Unlike traditional 2D drawings, these models allow stakeholders to visually engage with all aspects of the project, including structural, mechanical, electrical, and plumbing systems. This enhanced understanding is crucial for aligning project objectives and reducing design ambiguities.

Facilitation of Multi-Disciplinary Collaboration: BIM visualization acts as a collaborative platform that integrates inputs from architects, engineers, contractors, and owners. By providing a shared visual model, BIM enhances coordination between different disciplines, fostering a collaborative environment where all parties can work towards a common goal. This integration minimizes communication barriers and promotes a more efficient exchange of information, reducing the likelihood of errors or misinterpretations during project execution.

Proactive Identification of Clashes and Conflicts: The ability to conduct visual clash detection is a significant advantage of BIM models. By simulating the physical and functional components of a building in a virtual environment, project teams can identify potential clashes between various systems—such as mechanical, electrical, and plumbing—before they manifest on-site. This proactive identification of conflicts helps in mitigating risks, reducing costly rework, and minimizing project delays, ultimately leading to more efficient construction processes.

Real-Time Model Updates and Decision Support: BIM visualization allows for real-time updates to the project model, ensuring that all stakeholders have access to the most current information. This dynamic capability supports informed decision-making throughout the project lifecycle, as changes can be visualized instantly, and their impacts on cost, schedule, and resources can be assessed promptly. The ability to simulate different scenarios further enhances strategic planning and project control.

Optimization of Time and Cost Management: The visualization of BIM models contributes significantly to the optimization of time and cost management in construction projects. Through precise visual representation, project teams can analyze construction sequences, optimize workflows, and plan resource allocation more effectively. The ability to visualize material quantities and construction phases in a detailed manner aids in more accurate cost estimation and budget control, contributing to overall project efficiency.

Enhanced Client Communication and Stakeholder Engagement: For clients and non-technical stakeholders, visualizing the BIM model provides a clear and intuitive understanding of the project's design intent and progress. This capability facilitates meaningful engagement, enabling clients to provide timely feedback and participate in decision-making processes. Moreover, it helps align client expectations with the final project outcome, reducing the need for revisions and enhancing overall satisfaction.

Improved Safety and Risk Management: BIM visualization extends its benefits to safety planning by allowing construction teams to simulate site conditions, workflows, and potential hazards before construction begins. This proactive approach to safety enables the development of detailed safety protocols and risk mitigation strategies, reducing the likelihood of on-site accidents and ensuring compliance with health and safety regulations.

The strategic use of BIM model visualization in construction offers a multitude of advantages that extend beyond the traditional scope of design representation. By improving interdisciplinary collaboration, enhancing decision-making, optimizing project costs and timelines, and mitigating risks, BIM visualization serves as a pivotal tool in driving project success. Its role in fostering informed engagement among all stakeholders makes it indispensable for modern construction practices, leading to improved project outcomes, increased efficiency, and higher stakeholder satisfaction.

1.13. Coordination Between Stakeholders in BIM-Driven Projects

In construction projects, effective coordination between stakeholders is crucial for achieving timely and successful project delivery. Building Information Modeling (BIM) serves as a transformative tool in facilitating this coordination, ensuring that all project participants—ranging from architects and engineers to contractors and clients—are aligned throughout the project lifecycle. This section delves into the importance of stakeholder coordination in BIM environments and the ways in which it enhances collaboration, mitigates risks, and promotes project efficiency.

Importance of Stakeholder Coordination in BIM:

Stakeholder coordination refers to the seamless collaboration and communication between various parties involved in the construction process. In traditional construction practices, miscommunication or lack of alignment between stakeholders can lead to significant project delays, cost overruns, and inefficiencies. BIM mitigates these risks by acting as a centralized platform for sharing real-time information and design updates.

Coordination in a BIM-Driven Project:

BIM enables a more collaborative and coordinated approach to construction projects by providing a digital representation of the building's physical and functional characteristics. This shared environment fosters real-time information exchange and allows stakeholders to work together more effectively, improving decision-making and overall project outcomes.

Centralized Data and Information Sharing:

One of the fundamental advantages of BIM is its ability to serve as a centralized platform for all project-related information. All stakeholders can access the most up-to-date data within the model, including design changes, material specifications, schedules, and costs. This centralized data environment reduces the chances of miscommunication or errors due to outdated or incomplete information.

Example: When an designer updates the design in the BIM model, this change is instantly reflected across all relevant disciplines, allowing engineers and contractors to adjust their plans accordingly without delays.

Interdisciplinary Collaboration:

BIM enhances collaboration between various disciplines (e.g., architecture, structural engineering, MEP) by enabling them to work on a unified model. The collaborative nature of BIM ensures that all stakeholders can review and contribute to the model in real time, fostering better design integration and avoiding potential clashes between systems.

Example: Architect can ensure that their designs do not interfere with the MEP systems (such as ducts or wiring), reducing of conflicts during construction.

Improved Scheduling and Resource Allocation:

Coordination between stakeholders also extends to scheduling and resource management. BIM tools such as 4D scheduling (time) and 5D cost modeling help synchronize construction activities with project timelines and budgets. This ensures that all stakeholders are aware of project milestones and can plan their activities accordingly, avoiding bottlenecks or delays in the construction process.

Example: Contractors can use 4D BIM models to simulate construction sequences and identify the most efficient paths for material deliveries, labor scheduling, and equipment usage.

Change Management and Documentation:

BIM helps manage design changes more effectively by ensuring that all modifications are documented within the model and communicated to all stakeholders in real time. This prevents costly errors or delays caused by unapproved or untracked changes. The shared environment also ensures that all stakeholders have a record of the project's history, providing transparency and accountability.

Example: When a structural change is made, the BIM model automatically updates the relevant documentation and notifies all impacted stakeholders (e.g., MEP engineers, quantity surveyors) to adjust their plans accordingly.

Advantages of BIM-Driven Stakeholder Coordination:

Reduction of Errors and Rework: By ensuring that all stakeholders work from a single source of truth, BIM minimizes the risk of errors and rework. The ability to detect clashes and inconsistencies early in the design phase prevents costly changes during construction.

Increased Efficiency and Productivity: BIM fosters a more streamlined workflow, where tasks are clearly defined, and coordination between teams is optimized. This reduces downtime, ensures better resource allocation, and accelerates project timelines.

Cost Control and Budget Adherence: The enhanced visibility provided by BIM allows for more accurate cost forecasting and budget tracking. With all stakeholders aligned, there are fewer surprises related to cost overruns, leading to more financially successful projects.

Enhanced Client Satisfaction: By providing a transparent and easily understandable representation of the project, BIM improves client engagement and satisfaction. Clients are better informed throughout the project lifecycle and can provide input or approvals with greater confidence.

Risk Mitigation: Coordinating through BIM helps identify and mitigate risks early in the project. Whether through clash detection, real-time information sharing, or improved scheduling, stakeholders can proactively address issues before they escalate into larger problems.

Effective coordination between stakeholders is essential for the success of any construction project. By leveraging BIM, stakeholders can work in a more collaborative, transparent, and efficient manner. The integration of real-time information sharing, clash detection, and improved communication enhances project outcomes, ensuring that projects are delivered on time, within budget, and to the highest quality standards. BIM is transforming how teams work together in construction, making stakeholder coordination one of the most critical components of modern project management.

1.14. Key Stakeholders in a BIM Environment

Building Information Modeling (BIM) environments require a collaborative ecosystem where various stakeholders work together to achieve the project's objectives. Each stakeholder plays a distinct and interconnected role in leveraging BIM technology to streamline workflows, enhance accuracy, and deliver successful outcomes. Below is an in-depth analysis of the key stakeholders and their responsibilities within a BIM-enabled project framework.

1. Architects and Designers

Architects and designers are central to the BIM process, as they are responsible for conceptualizing and creating the overall design intent and aesthetic vision of the project.

Their role extends beyond traditional design to include integrating BIM tools for improved visualization, simulation, and collaboration.

- **Responsibilities**: Architects use BIM to develop detailed models that capture the project's geometry, spatial relationships, and aesthetic details. They collaborate with other stakeholders to ensure the design aligns with functional, structural, and cost parameters. BIM tools enable architects to visualize the impact of design changes in real-time, ensuring seamless coordination with engineers and contractors.

- **Impact of BIM**: The ability to integrate sustainability parameters into the design phase is one of the significant advantages BIM offers to architects. Tools like energy modeling and daylight simulations allow architects to make informed decisions that align with environmental and regulatory standards.

- **Collaboration**: Architects act as the primary point of contact for design-related queries and ensure that their vision is accurately communicated and implemented by the project team.

2. Structural and MEP Engineers

Structural and mechanical, electrical, and plumbing (MEP) engineers are critical stakeholders who focus on the technical feasibility and integration of the project's systems. Their role involves designing structural frameworks and essential building systems while ensuring compatibility with the architectural design.

- **Responsibilities**: Structural engineers develop models that account for load-bearing elements, stability, and compliance with safety standards. MEP engineers create models for the mechanical, electrical, and plumbing systems, ensuring that these are efficiently integrated into the building design without conflicts.

- **Impact of BIM**: BIM tools such as clash detection and system integration ensure that the designs produced by structural and MEP engineers are error-free and optimized. By identifying potential conflicts, such as overlapping ducts or misaligned load paths, engineers can resolve issues in the virtual environment, avoiding costly delays and rework during construction.

- **Collaboration**: Engineers frequently interact with architects and contractors to refine designs based on practical constraints and site conditions. BIM's centralized data repository fosters better communication and decision-making among these stakeholders.

3. Contractors and Subcontractors

Contractors and subcontractors are responsible for translating the BIM models into physical structures. Their role involves managing construction activities while ensuring adherence to proposed timelines, budgets, and quality standards.

- **Responsibilities**: Contractors use BIM for construction planning, scheduling, and resource allocation. They rely on detailed models to understand the sequence of construction activities, identify potential risks, and optimize logistics. Subcontractors, on the other hand, use specialized BIM data to execute specific tasks, such as electrical installations or plumbing.

- **Impact of BIM**: By leveraging 4D BIM (time-based modeling), contractors can visualize project timelines and identify bottlenecks before construction begins. Additionally, BIM's integration with construction management software enables real-time progress tracking and ensures that on-site activities remain aligned with the project plan.

- **Collaboration**: Contractors collaborate with architects, engineers, and project owners to ensure that construction aligns with the project's design intent and functional goals. They also coordinate with subcontractors to ensure consistent quality and adherence to standards.

4. Clients and Project Owners

Clients and project owners provide the strategic direction, financial backing, and overall objectives for the project. Their involvement is critical in defining the project's scope and ensuring that the final deliverables meet end-user requirements.

- **Responsibilities**: Clients establish the project's goals, budget, and timeline. They play a key role in approving designs, changes, and progress milestones. In a BIM environment, clients can actively participate in the decision-making process by accessing models and visualizations that provide a clear understanding of the project's progress and outcomes.

- **Impact of BIM**: BIM enhances transparency and accountability, allowing clients to track the project's status in real-time. Features like cost estimation and lifecycle management enable clients to make informed decisions about budgets, material selection, and long-term maintenance strategies.

- **Collaboration**: Clients work closely with architects, contractors, and quantity surveyors to ensure that the project aligns with their expectations. Their feedback is integral to refining designs and addressing potential issues during the early phases of the project.

5. Quantity Surveyors and Cost Managers

Quantity surveyors and cost managers are responsible for overseeing the financial aspects of the project. Their role includes cost estimation, budget control, and ensuring that the project remains financially viable.

- **Responsibilities**: Quantity surveyors use BIM to extract accurate quantities of materials and labor from the models, enabling precise cost estimations. Cost managers monitor expenses and ensure that the project remains within budget throughout its lifecycle.

- **Impact of BIM**: BIM's automated quantity take-offs and cost estimation features significantly reduce errors and improve efficiency. By integrating cost data into the

BIM model (5D BIM), surveyors can provide real-time updates on financial metrics, helping stakeholders make proactive decisions.

- **Collaboration**: Quantity surveyors collaborate with project owners, contractors, and engineers to ensure that financial constraints are respected without compromising on quality or design intent. BIM's centralized platform enhances their ability to share cost data and recommendations effectively.

1.15. Comparing BIM and 2D AutoCAD in Terms of Cost, Time, and Efficiency

The transition from traditional 2D AutoCAD to Building Information Modeling (BIM) has had a transformative impact on the construction industry, particularly in terms of cost management, time efficiency, and overall project efficiency. Although 2D AutoCAD has served as a reliable instrument for many years, especially in drafting and design, its shortcomings in handling the intricacies of contemporary construction projects have become more apparent. Conversely, BIM presents a more holistic, data-centric methodology to project management by unifying design, cost analysis, scheduling, and resource allocation within a singular digital framework.

1. Cost Management:

Two-dimensional AutoCAD, while proficient in generating flat drawings, does not possess the functionality to seamlessly incorporate cost management within the design workflow. In the context of 2D AutoCAD, cost estimation is generally performed manually or via distinct software, frequently depending on calculations made after the design is completed along with the use of spreadsheets. This labor-intensive method of deriving quantity takeoffs—the essential materials needed for construction—is prone to inaccuracies and human mistakes, potentially leading to budget excesses and project delays. Eastman et al. (2011) emphasized that the fragmented nature of 2D AutoCAD-based cost management often leads to inconsistencies between the design and the project budget, causing unnecessary rework and cost adjustments as the project progresses.

Conversely, Building Information Modeling (BIM) facilitates automated quantity takeoffs, which are inherently connected to the three-dimensional model. This interconnectedness ensures that any alterations in the design are promptly mirrored in the cost assessments, enabling project managers to modify budgets and resources in real-time. Azhar et al. (2012) highlight that BIM's ability to automate these processes significantly reduces human error and enhances cost predictability, making it a more reliable tool for cost management. Additionally, BIM allows for the inclusion of lifecycle costs, helping stakeholders understand the total cost of a building over its entire lifecycle, including maintenance and operations—a feature that is absent in 2D AutoCAD.

2. Time Efficiency:

Time management is a critical aspect of construction projects, and traditional tools like 2D AutoCAD often struggle to keep pace with the dynamic nature of modern construction environments. Within a 2D AutoCAD framework, modifications to the design necessitate manual updates in associated documents, including schedules, cost estimates, and resource distributions. This process of manual updating is labor-intensive and heightens the probability of delays. If a design change is made late in the project, the entire cost and scheduling process must be revisited, which can introduce delays and lead to miscommunication among stakeholders.

Conversely, the integration of design, scheduling, and cost data in BIM facilitates instantaneous updates and negates the necessity for manual synchronization across various systems. This feature is especially advantageous when addressing changes during the project lifecycle. For instance, if a modification arises in one segment of the construction process, BIM automatically adjusts the entire project timeline, enabling project managers to reallocate resources and implement necessary changes to mitigate delays. Kocakaya et al. (2019) illustrated that construction projects employing BIM encountered fewer delays than those relying on 2D AutoCAD, primarily due to BIM's capacity to furnish real-time data and avert expensive scheduling conflicts.

Additionally, BIM's capability for 4D modeling (which integrates time and scheduling into the 3D model) equips project managers with a visual depiction of the construction sequence. This visual representation aids stakeholders in recognizing potential scheduling conflicts and making well-informed decisions regarding project timelines. The ability to visualize the construction progression over time confers a substantial advantage to BIM over 2D AutoCAD, where project managers must depend on static, disconnected documents to oversee time management.

3. Overall Project Efficiency:

BIM's integrative nature allows for greater project efficiency by ensuring that all stakeholders—architects, engineers, contractors, and clients—are working with the same set of data. This cooperative setting diminishes the chances of miscommunication and guarantees that project decisions are informed by precise, current information. In a conventional 2D AutoCAD workflow, each participant may operate from their distinct set of drawings or documents, which can result in inconsistencies when modifications occur. For example, an alteration implemented by the architect might not be reflected in the contractor's iteration of the plans, leading to expensive errors and delays.

Conversely, BIM's centralized framework enables all participants to access and collaborate on the same model simultaneously. Any modifications to the model are instantly visible to all involved parties, ensuring alignment among them. This degree of collaboration aids in averting mistakes and reduces the necessity for rework, ultimately enhancing overall project efficiency. Azhar et al. (2012) found that projects using BIM experienced fewer errors and required less rework compared to projects using 2D AutoCAD, largely due to BIM's ability to integrate real-time collaboration and decision-making.

Another area where BIM significantly improves efficiency is in sustainability and lifecycle management. By using 6D BIM (which integrates sustainability and lifecycle data), project teams can simulate energy usage, environmental impacts, and long-term maintenance costs. This allows for better decision-making during the design phase, ensuring that the building is not only cost-effective during construction but also throughout its entire lifecycle. This capability is not available in 2D AutoCAD, which primarily focuses on the design and construction phases, leaving out considerations for long-term operational efficiency.

While 2D AutoCAD has been a reliable tool for drafting and design, its limitations in integrating cost, scheduling, and real-time collaboration have made it less suitable for the complex demands of modern construction projects. BIM's holistic approach to construction project management—integrating design, cost, time, and collaboration—provides a more efficient, accurate, and collaborative environment, resulting in significant improvements in cost management, time efficiency, and overall project outcomes. As construction projects become more complex and the industry increasingly embraces digitalization, BIM is poised to become the standard for efficient, data-driven construction management.

1.16. Broader Benefits of Digitalization in Construction Economics

The digital transformation of the construction industry has brought about a profound shift in how projects are managed, executed, and delivered. In addition to the advantages of enhanced cost management and time efficiency provided by technologies such as Building Information Modeling (BIM), digital innovations are fundamentally altering the construction landscape by fostering advancements in design, collaboration, data sharing, and sustainability practices. The adoption of technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), cloud-based platforms, and digital twins is revolutionizing the construction industry, leading to enhanced efficiency, reduced costs, and improved project outcomes.

1. Real-Time Data Collection and Decision-Making

Traditionally, construction management relied on manual data collection and historical records, often resulting in delays when responding to emerging issues on construction sites. The integration of IoT devices has fundamentally changed this dynamic by providing real-time data from construction sites. IoT sensors can track variables such as machinery performance, material delivery, worker productivity, and environmental conditions. This influx of real-time data allows project managers to make informed, timely decisions, mitigating the risk of delays and improving overall project efficiency. Kankhva et al. (2021) highlight that IoT technology enables a more proactive approach to construction management, where issues can be addressed in real-time, thus reducing inefficiencies and improving project outcomes. For instance, IoT sensors can notify managers when equipment is malfunctioning or when materials are delayed, allowing them to adjust schedules or allocate resources more effectively. This data-driven approach minimizes downtime and reduces the likelihood of errors, making construction projects more efficient and cost-effective.

2. Artificial Intelligence and Predictive Analytics

Artificial Intelligence (AI) represents a significant advancement in digital technologies, reshaping the economics of construction by utilizing extensive datasets to enhance decision-making processes and forecast potential obstacles. AI-powered predictive analytics tools can analyze historical data, real-time information from IoT devices, and BIM models to identify patterns and trends that may not be immediately apparent to human managers. Through the application of AI algorithms, project supervisors are able to foresee equipment failures, material shortages, or project delays, which allows them to schedule maintenance or acquire necessary resources proactively, thereby mitigating the risk of expensive downtimes.

The capacity of AI to optimize the allocation of resources plays a crucial role in minimizing waste and enhancing the overall operational efficiency of construction endeavors. Kankhva et al. (2021) highlight that AI innovations assist construction enterprises in optimizing labor distribution, streamlining material usage, and minimizing surplus inventory. This optimization not only improves cost efficiency but also contributes to more sustainable construction practices, as fewer resources are wasted throughout the project lifecycle.

3. Digital Twins and Enhanced Project Monitoring

The integration of digital twins with BIM technology is another breakthrough in construction economics. A digital twin is a virtual replica of a physical asset, process, or system that is updated in real-time to reflect changes in the actual environment. When integrated with BIM, digital twins afford project managers an extensive, real-time perspective of construction progress, enabling them to closely observe project developments and react promptly to changes as they arise. Salem and Dragomir (2022) contend that digital twins offer considerable advantages in the areas of forecasting, resource allocation, and maintenance strategy. By delivering current information on the status of a construction project, digital twins empower managers to identify potential challenges prior to their escalation into major issues. For instance, should there be a setback in material delivery, the digital twin can recalibrate the project schedule and recommend alternative approaches, thereby ensuring that the project stays on course. This ability to visualize and simulate various scenarios enhances project oversight and contributes to more accurate cost and time management.

Furthermore, digital twins facilitate enhanced lifecycle management. Once a building is completed, the digital twin continues to serve as a record of the building's components and systems, providing valuable data for future maintenance and operation. This digital documentation assists facility managers in planning preventive maintenance activities, thereby prolonging the lifespan of the building's elements and minimizing long-term operational expenses.

4. Collaboration and Data Sharing

Digitalization has also significantly improved collaboration and communication among the various stakeholders involved in construction projects. Historically, construction teams operated independently, with architects, engineers, contractors, and clients often utilizing disparate sets of data or designs. This disjointed approach regularly resulted in miscommunication, inaccuracies, and the necessity for rework, all of which exacerbated project delays and budget overruns.

With the advent of BIM and cloud-based platforms, all stakeholders now have access to a centralized data repository, enabling real-time collaboration and information sharing. Zulu et al. (2023) highlight that cloud-based systems enhance project efficiency by ensuring that every participant in the construction project is utilizing the same, current information, irrespective of their physical location. This dissolution of information silos diminishes the chances of errors, enhances decision-making processes, and aids in maintaining project timelines.

Cloud-based platforms further support remote collaboration, enabling teams situated in different geographical areas to work cohesively. This functionality is especially advantageous in large-scale construction initiatives that involve numerous teams distributed across multiple locations. The capacity for remote collaboration guarantees that all participants remain aligned with the project's objectives and schedules, thereby further enhancing project results.

5. Sustainability and Environmental Impact

Digitalization has significantly enhanced the construction sector's ability to adopt sustainable methodologies. Instruments such as 6D BIM empower architects and engineers to assess and predict the long-term environmental consequences of various design and material selections. By simulating diverse scenarios, including energy usage, waste production, and emissions, construction companies are enabled to make better-informed decisions regarding the reduction of their ecological impact.

Byun and Sohn (2020) assert that employing BIM for sustainability assessments aids architects in creating buildings with improved energy efficiency, thereby lowering both the construction and operational expenses associated with a project. Furthermore, digital solutions facilitate meticulous resource allocation, guaranteeing that materials are procured in appropriate amounts and delivered punctually, consequently reducing waste. These environmentally friendly practices not only mitigate the ecological repercussions of construction activities but also yield enduring financial benefits.

The overarching advantages of digitalization in construction economics encompass much more than merely cost control and time optimization. Through the adoption of digital tools like BIM, IoT, AI, cloud-based platforms, and digital twins, the construction industry is experiencing improvements in real-time decision-making, collaboration, sustainability, and project monitoring. These technologies are not only driving efficiencies but are also setting new standards for how construction projects are designed, executed, and managed. As the industry continues to embrace digitalization, the future of construction economics will likely see even greater opportunities for innovation, cost savings, and sustainable growth.

1.17 Research Objectives:

- To evaluate the effectiveness of digital tools in enhancing accuracy, efficiency, and cost management processes compared to traditional methods.
- To assess the impact of real-time project updates facilitated by digital tools on stakeholder satisfaction and overall project outcomes in construction cost management.
- To analyze the role of digitalization in reducing miscommunication among stakeholders and improving coordination in construction projects.
- To investigate the challenges and barriers to adopting digital technologies in construction, including cost implications, skill gaps, and organizational resistance to change.
- To develop policy recommendations that promotes the widespread adoption of digital solutions in the construction industry.

Conclusion:

In conclusion, the construction industry is at a pivotal moment, facing the challenges of inefficiencies, delays, and cost overruns. Conventional techniques such as 2D AutoCAD, although beneficial in previous eras, fail to adequately address the increasing intricacy of contemporary projects. Building Information Modeling (BIM) presents a revolutionary approach by uniting design, cost analysis, and scheduling within a singular framework. By facilitating real-time cooperation, automation, and improved project oversight, BIM has the potential to markedly enhance construction productivity, minimize inaccuracies, and encourage stronger collaboration among involved parties. The implementation of BIM represents an essential move towards the modernization of the sector, although obstacles like elevated expenses and skill deficiencies continue to require attention. This research will explore the potential of BIM and provide insights on how it can reshape the future of construction project management.

CHAPTER II:

REVIEW OF LITERATURE

2.1 Theoretical Framework

The theoretical framework for your research is based on the integration of theories and principles of digitalization, construction economics, and cost management. It provides a structured lens to understand the adoption and impact of digital tools, specifically Building Information Modeling (BIM), in construction cost management. The framework is designed to explore relationships between the adoption of digitalization and its effects on efficiency, accuracy, collaboration, and overall project success in the construction industry.

Key Components of the Theoretical Framework

Technology Acceptance Model (TAM): The TAM serves as a foundation to evaluate how professionals in the construction industry perceive and adopt digital tools for cost management. It considers key variables such as:

Perceived Usefulness: The extent to which users believe that digital tools improve efficiency, accuracy, and decision-making in cost management.

Perceived Ease of Use: The degree to which users find these tools user-friendly and compatible with their existing workflows.

Behavioral Intention to Use: The willingness of construction professionals to integrate digital solutions into their practices based on perceived benefits and ease of use.

Diffusion of Innovations (Rogers, 2003): This theory helps analyze the adoption curve of digital tools like BIM across different segments of the construction industry. It identifies:

Innovators and early adopters who actively integrate advanced digital technologies.

Barriers to adoption, such as high implementation costs and resistance to change, that hinder the spread among later adopters.

Resource-Based View (RBV): RBV underscores the strategic importance of digital tools as valuable organizational resources. It posits that the effective deployment of BIM and other technologies can create a competitive advantage by:

Enhancing resource management through accurate cost estimation and monitoring.

Improving project outcomes by reducing waste and optimizing resource allocation.

Systems Theory in Construction Management: This theory provides a framework for understanding how digitalization integrates with various subsystems in construction, including procurement, budgeting, and project monitoring. BIM is viewed as a central system that connects and coordinates these subsystems to achieve project goals efficiently.

Lifecycle Cost Management Principles: Lifecycle cost management principles guide the analysis of how digital tools like BIM influence cost management across project phases—from initial estimation to final reporting. The focus is on achieving cost efficiency while ensuring quality and sustainability.

2.2 Summary:

The construction industry, known for its traditional reliance on manual processes, is undergoing a transformative shift due to the increasing adoption of digital technologies. This transformation, often referred to as digitalization, is characterized by the integration of Building Information Modeling (BIM), Internet of Things (IoT), artificial intelligence (AI), cloud-based platforms, and other advanced tools to enhance efficiency, transparency, and cost management in construction projects. These technologies are becoming essential for improving collaboration, reducing project delays, optimizing resource allocation, and managing costs effectively across various construction stages.

In the context of construction cost management, the implementation of digital tools like BIM has significantly impacted how projects are planned, monitored, and executed. BIM, in particular, has revolutionized the industry by providing a comprehensive platform that integrates 3D modeling, cost estimation, project scheduling, and lifecycle management. This has allowed construction professionals to better visualize projects, manage resources, and mitigate risks associated with cost overruns. However, despite its benefits, the construction industry faces challenges in adopting BIM fully, such as resistance to change, high implementation costs, and lack of skilled professionals. These barriers must be addressed to ensure the widespread adoption of BIM and other digital tools.

This review of literature explores the role of digitalization in construction economics, focusing on the integration of BIM and other digital tools for effective construction cost management. It provides a detailed examination of studies that highlight the transformative effects of digitalization on the construction sector, compare the use of traditional methods like 2D AutoCAD with modern BIM practices, and discuss the challenges associated with the adoption of these technologies. Furthermore, the review explores advanced applications of BIM and digital technologies, such as digital twins and automation, which are pushing the boundaries of project management and cost efficiency. In recent years, researchers have increasingly focused on how digital tools can be leveraged to address the persistent issues of inefficiency, delays, and cost overruns in construction projects. As construction companies face growing pressure to deliver projects on time and within budget, digitalization presents an opportunity to optimize processes and achieve better outcomes. The integration of technologies like BIM not only facilitates more accurate cost estimations but also enhances decision-making and collaboration among stakeholders, contributing to more sustainable and efficient construction practices. This literature review is divided into several key sections, starting with a focus on BIM in construction cost management, where studies explore the benefits and challenges of using BIM to streamline cost-related activities. The next section covers digital transformation in construction, highlighting the overall impact of digital tools on project management and organizational efficiency. Following this, a comparison between 2D AutoCAD and BIM is presented, emphasizing the advantages of BIM over traditional design methods. The review then addresses the challenges and barriers to BIM adoption, before concluding with an exploration of advanced applications of BIM and digital tools, showcasing innovative uses of technology in the construction industry. Through this review, the complexities and opportunities associated with the digital transformation of the construction industry will be critically examined, providing insights into how the adoption of these technologies can improve construction economics and project outcomes.

2.3 Digital Transformation in Construction:

Kagan (2021) The growing role of digital technologies in the organizational and technological design of the construction industry has become a pivotal area of focus in recent research. This study emphasizes that integrating digital tools into construction processes is no longer optional but essential for achieving modernization and improving efficiency in both design and production activities. The integration of these tools offers opportunities to enhance precision, reduce redundancy, and streamline workflows, which are crucial in meeting the demands of a competitive and fast-paced industry. However, the study identifies significant challenges that impede this transition, particularly the limitations of existing automated systems used for developing design documentation. These systems are often rigid, lacking the flexibility to adapt to diverse project requirements, and function in isolation, creating silos that inhibit collaboration and efficient communication among stakeholders.

The research underscores the need for innovative digital solutions capable of addressing these inefficiencies. It highlights the importance of focusing on the digitalization of design processes, as this stage lays the groundwork for defining the essential characteristics and parameters of construction projects. Without advancements in this area, the industry risks being held back by outdated practices that limit its ability to deliver projects efficiently and cost-effectively. The study aligns its findings with the digital economy initiatives introduced by the Russian government, which advocate for embedding digital technologies across the construction sector. These initiatives aim to reduce costs, accelerate project timelines, and improve the overall quality of construction outcomes. By doing so, they offer a roadmap for fostering a more integrated, efficient, and forward-looking construction industry. Ultimately, the study emphasizes that adopting digital tools is not just about technological progress but about addressing fundamental issues in the industry. This includes improving collaboration, ensuring data consistency, and creating a more agile approach to managing complex construction projects. By embracing these changes, the construction sector can better meet the growing expectations of clients, stakeholders, and regulatory frameworks while positioning itself for sustainable growth in an increasingly digital world.

Koscheyev and Hakimov (2019) The use of digital technologies in public procurement management within the Russian construction industry has emerged as a transformative approach to improving the transparency, efficiency, and competitiveness of procurement processes. This research underscores the strategic significance of public procurement as a driver of national economic growth, particularly within the construction sector. Public projects often play a pivotal role in supporting small and medium enterprises (SMEs), which are integral to the broader economic landscape. By leveraging digital technologies, the procurement process can be redefined to address traditional inefficiencies and better align with global standards. The study delves into the influence of global trends, including the adoption of electronic procurement systems, blockchain technology, smart contracts, and neural networks, on enhancing public procurement management. Electronic procurement systems simplify the bidding process, allowing for streamlined submissions and evaluations. Blockchain technology ensures data integrity and traceability, reducing the potential for manipulation or corruption. Smart contracts automate contractual agreements, enabling precise and timely execution of terms, while neural networks facilitate advanced data analytics, enabling informed decision-making throughout the procurement cycle. Together, these tools significantly reduce bureaucratic hurdles, enhance transparency, and improve accountability, contributing to a more efficient and trustworthy procurement environment. Despite the potential benefits, the study identifies critical challenges that must be addressed to fully implement digital technologies in public procurement. A significant barrier is the lack of standardized digital platforms that can be universally adopted across the procurement system. Regulatory reforms are also necessary to accommodate the technical and operational changes introduced by digital tools. Additionally, the digital literacy of procurement professionals remains a pressing concern, as many individuals lack the necessary skills to effectively utilize advanced technologies. Without addressing these foundational issues, the full potential of digital transformation in public procurement cannot be realized. The authors conclude by advocating for the continued development and refinement of digital tools to create a fully integrated public procurement system in Russia. They emphasize the importance of aligning these efforts with the global digital economy to ensure the competitiveness of Russia’s construction sector. By fostering an ecosystem that prioritizes transparency, efficiency, and inclusivity, the integration of digital technologies can serve as a catalyst for economic growth, benefiting not only large-scale public projects but also SMEs that rely on fair and efficient procurement systems. This comprehensive approach will enable Russia’s construction industry to remain competitive on a global scale while addressing long-standing issues in procurement management.

Chen and Luo (2014) proposed a BIM-based construction quality management model aimed at addressing challenges in quality control throughout the construction process. The study highlighted the limitations of traditional quality control methods, which often relied on scattered and complex quality codes, lack of integration between design and construction phases, and inadequate attention to process-level quality. By integrating Building Information Modeling (BIM) with a Product, Organization, and Process (POP) framework, the authors developed a 4D BIM-based application capable of dynamically managing quality data and providing real-time insights into construction progress and compliance.

The proposed model enables seamless interaction between design data, construction schedules, and quality control requirements, ensuring consistent information flow from the design phase to the construction stage. It incorporates features such as automated inspection planning, compliance analysis, and feedback mechanisms, reducing errors and facilitating better decision-making. A case study of the Wuhan International Expo Center demonstrated the model's effectiveness in improving quality management and achieving project milestones on schedule. The study concludes that BIM, when combined with structured quality frameworks, has the potential to revolutionize quality management in construction projects, although its practical implementation requires overcoming challenges related to temporary structures, mobile device compatibility, and integration with existing workflows.

Begić and Galić (2021**)** conducted a systematic review that focuses on the evolution of the construction industry in the context of Construction 4.0, emphasizing its reliance on Building Information Modeling (BIM) 4.0. The study analyzes how the fourth industrial revolution (4IR) has influenced construction practices, particularly through the integration of advanced digital tools and technologies like BIM, the Internet of Things (IoT), and Big Data (BD). These technologies have been identified as key drivers of real-time monitoring, predictive data analysis, and streamlined construction planning, marking a significant shift from traditional construction methods.

The authors explore the widespread adoption of BIM in the pre-construction phase, which has revolutionized tasks such as design visualization, cost estimation, and scheduling. However, they highlight a critical gap in BIM's application during the construction phase. This underutilization is attributed to challenges like the fragmented nature of the construction industry, the lack of skilled personnel, and insufficient interoperability among digital tools. The study underscores that the transition towards BIM 4.0—defined by the integration of IoT and Big Data into BIM systems—can enhance the real-time data exchange required for efficient construction-phase management. The review discusses the potential benefits of adopting BIM 4.0, including increased project efficiency, reduced resource wastage, and improved decision-making through predictive analytics. The authors argue that the integration of 4IR technologies with BIM has the potential to address long-standing issues in construction, such as delays, cost overruns, and poor communication among stakeholders. However, they also acknowledge the barriers to adoption, such as high implementation costs, data security concerns, and the need for robust training programs. The study concludes by emphasizing the necessity of industry-wide initiatives and policy reforms to encourage the adoption of Construction 4.0 technologies. They propose that collaborative frameworks between government, academia, and industry practitioners can accelerate the transition towards fully integrated BIM 4.0 systems, thereby driving innovation and sustainability in construction practices.

Smith (2014) provides an in-depth examination of the global strategies for implementing Building Information Modeling (BIM) in the construction industry, emphasizing its transformative potential for improving project efficiency, reducing costs, and enhancing collaboration. Despite its availability for over a decade, the adoption of BIM has been slower than anticipated, especially when compared to other industries like manufacturing. The research identifies several drivers that facilitate BIM implementation, including government mandates, the establishment of national standards, legal protocols, and coordinated leadership within the construction sector. The study showcases successful case studies from regions like North America, Scandinavia, and the United Kingdom, where governments have played a critical role in mandating the use of BIM for public projects. These examples demonstrate how clear implementation frameworks and coordinated efforts can accelerate BIM adoption across the industry. For instance, the United Kingdom's government strategy, which included deadlines for BIM compliance and the development of standardized BIM protocols, is highlighted as a model for other regions to follow. However, the research also delves into the challenges hindering BIM implementation globally. A key barrier is the lack of interoperability between different BIM software platforms, which complicates collaboration and data exchange across project stakeholders. Additionally, fragmented adoption strategies across regions and a lack of consistent training and education for construction professionals pose significant hurdles. These issues prevent the industry from fully realizing the potential benefits of BIM. Smith concludes that for BIM to achieve widespread adoption and impact, the construction industry must prioritize global coordination, establish robust standards, and provide adequate training. Furthermore, the development of a strong business case for BIM adoption is essential to convince stakeholders of its long-term value. The study emphasizes that while BIM has already demonstrated its capability to revolutionize construction processes, its full potential can only be unlocked through unified efforts at both regional and global levels.

Nawari (2012) examined the implementation and advancement of Building Information Modeling (BIM) standards within off-site construction to improve efficiency, sustainability, and integration across the construction process. The study highlights BIM's potential to streamline prefabrication by enabling digital modeling, which allows for accurate visualization, cost estimation, project planning, and the management of a building's lifecycle. Nawari argues that the success of BIM in off-site construction relies on standardizing data exchanges and ensuring interoperability among various stakeholders. The research focuses on the development of the Information Delivery Manual (IDM), Model View Definition (MVD), and Industry Foundation Classes (IFC) as key components of BIM standards. These frameworks ensure that relevant information is captured and exchanged efficiently between architects, engineers, manufacturers, and contractors. The study also outlines the challenges in advancing BIM standards, such as the need for standardized workflows and the lack of integrated digital exchanges across trades. Additionally, Nawari identifies opportunities for automating off-site construction processes, which could reduce costs, improve construction quality, and address risks associated with traditional construction methods. The paper concludes that adopting a robust BIM standard in off-site construction facilitates seamless collaboration, improves decision-making, and enhances project outcomes. By standardizing information exchanges and leveraging the full capabilities of BIM, the construction industry can achieve significant advancements in prefabrication, aligning with the broader goals of efficiency and sustainability.

Koscheyev et al. (2019) The digital transformation of construction organizations is a critical factor in enhancing competitiveness and efficiency in the sector. This study explores how the adoption of digital technologies can fundamentally reshape construction processes, driving improvements across project lifecycles and creating more sustainable economic outcomes. Digital transformation is presented as a necessary evolution, capable of reducing the life cycle of investment-construction projects, optimizing resource utilization, and fostering a deeper understanding of both production processes and evolving market demands. By adopting these changes, construction organizations can better position themselves to meet the challenges of an increasingly dynamic and competitive industry landscape. The research identifies a variety of digital tools and strategies that are central to this transformation. The integration of digital platforms, for example, enables transparent information exchange, improving collaboration among stakeholders and reducing delays caused by miscommunication. Organizational structures must also adapt to support digital workflows, ensuring alignment between technological advancements and operational processes. The rationalization of technological processes, supported by innovations like digital procurement systems and materials management tools, allows construction companies to reduce waste and enhance operational efficiency. Advanced technologies such as Building Information Modeling (BIM), drones, and industrial robots are highlighted for their role in improving productivity and accuracy in construction activities. BIM, in particular, is instrumental in enabling data-driven decision-making and facilitating seamless collaboration across project teams, while drones and robotics bring significant efficiencies to site monitoring, material handling, and other labor-intensive tasks. Despite the potential benefits of these advancements, the study acknowledges persistent challenges in the sector's digital transformation journey. One major issue is the fragmented use of digital tools, where organizations adopt technologies in isolation rather than as part of a cohesive strategy. This lack of integration diminishes the potential gains from digitalization. Resistance to change is another significant barrier, as employees and management may hesitate to embrace new processes and technologies due to unfamiliarity or concerns about disruptions to traditional workflows. Addressing these challenges requires a cultural shift within organizations, fostering an environment that values innovation and continuous improvement. The authors conclude that for construction companies to succeed in the digital economy, they must adopt a comprehensive and well-defined strategy. This strategy should align digital capabilities with business goals, emphasizing areas such as client collaboration, process optimization, and ongoing digital education. By fostering a culture of adaptability and innovation, companies can unlock the full potential of digital tools, ensuring long-term growth and sustainability in a rapidly changing industry. The research underscores the importance of viewing digital transformation not as a one-time initiative but as an ongoing process that requires consistent effort, investment, and commitment to stay ahead in the competitive global market.

Zulu et al. (2023) A systematic literature review explored the relationship between digitalization and productivity in the construction industry, highlighting key mediating factors that influence this connection. These factors include improvements in safety and well-being, enhanced planning, increased collaboration, waste reduction, skill development, and error minimization. The study emphasized the construction sector's historically slow adoption of digital technologies, despite clear evidence of their benefits in improving productivity. The review revealed that digitalization enhances communication, collaboration, and accuracy in construction processes, resulting in cost and time savings. However, barriers such as limited awareness and a lack of empirical studies demonstrating tangible benefits continue to hinder adoption. The authors called for more quantitative research to establish concrete evidence of digitalization's impact on productivity and stressed the urgency for construction firms to integrate digital tools into their workflows. By doing so, firms can overcome inefficiencies, modernize operations, and position themselves for sustained growth in a competitive industry.

Liu et al. (2023) A conceptual project governance model was developed to promote digitalization in construction projects, addressing the industry's slow pace of digital transformation. The study identified key barriers, including organizational resistance, stakeholder skepticism, and technical difficulties in implementing technologies like BIM and IoT. The authors proposed a governance framework centered on three dimensions: stakeholder integration, lifecycle integration, and project management knowledge integration. These dimensions operate across institutional, organizational, and behavioral levels to ensure a holistic approach. A detailed case study illustrated how this model aligns project objectives with stakeholder needs, fosters collaboration, and streamlines processes to support the adoption of digital technologies. The findings highlight that successful digitalization in construction requires more than technological advancements; it demands substantial organizational change underpinned by a robust governance structure that facilitates adaptation and ensures alignment with project goals.

Kankhva et al. (2021) An in-depth analysis explored the transformation and future prospects of the construction industry within the framework of the digital economy, emphasizing the need for full digital integration to align the sector with the broader digital ecosystem. The study highlights that technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), and cloud-based platforms are pivotal in driving this transformation. These tools enhance project management, cost control, and real-time monitoring while fostering seamless collaboration among key stakeholders, including designers, engineers, contractors, and policymakers. By enabling efficient data exchange and coordinated decision-making, these technologies play a critical role in modernizing construction processes and meeting the demands of increasingly complex projects. The research underscores the necessity of integrating digital information models for investment and construction projects with state information systems to improve operational efficiency. Such integration is key to elevating the quality of capital construction projects and optimizing urban environments through streamlined planning, execution, and maintenance processes. This approach not only ensures better resource utilization but also aligns construction projects with broader urban development goals, creating smarter, more sustainable cities. Despite these advancements, the study identifies persistent challenges that hinder the full realization of digitalization. Fragmented information systems and the lack of unified data platforms pose significant barriers to effective collaboration and data sharing. Moreover, complexities in ensuring interoperability across various platforms and technologies further slow down the adoption process. The regulatory framework, while evolving, remains insufficiently cohesive to support the widespread and swift implementation of digital tools. Addressing these issues will require concerted efforts to develop standardized platforms, foster industry-wide collaboration, and create a regulatory environment that encourages innovation and integration. By overcoming these challenges, the construction sector can fully leverage digital technologies to drive efficiency, quality, and sustainability in its operations.

Puolitaival and Kähkönen (2022) An in-depth investigation examined the evolving role of digital technologies in executing construction management responsibilities, shedding light on the construction industry\u2019s slow progress in digitalization compared to sectors like manufacturing and logistics. Through a combination of document analysis and a systematic literature review, the study identified eight key responsibilities central to construction management: time, cost, quality, health and safety, environmental management, resource allocation, contract management, and human resources/process development. These responsibilities form the backbone of construction operations and highlight the complexity of coordinating diverse tasks within a single project.The research categorized digital technologies into three groups: communication and enabling technologies, technologies combining hardware and software into intelligent systems, and data technologies. These categories include tools such as Building Information Modeling (BIM), digital twins, augmented reality (AR), and the Internet of Things (IoT), all of which play a crucial role in streamlining construction tasks. For instance, BIM and digital twins facilitate better planning and collaboration, while AR enhances on-site operations through visual overlays, and IoT enables real-time monitoring of construction activities and resource usage. Together, these technologies not only improve efficiency but also address challenges such as cost overruns, project delays, and quality inconsistencies. Despite the growing recognition of these tools\u2019 potential, the study concludes that their integration into construction management practices remains in its early stages. While BIM has gained traction, other advanced technologies like digital twins and AR are yet to be fully adopted on a large scale. The authors emphasize the need for further research and development to explore the optimal ways to implement and integrate these technologies into the construction workflow. This integration will be essential to unlocking the full benefits of digitalization, ensuring that the construction industry can meet the demands of increasingly complex projects while maintaining high standards of efficiency, safety, and sustainability.

2.4 BIM in Construction Cost Management:

Vitásek and Matějka (2017) A study explored the application of Building Information Modeling (BIM) for automating quantity takeoffs (QTO) and cost estimation in transport infrastructure construction projects in the Czech Republic. The research highlights BIM's potential to streamline traditionally labor-intensive processes by automating the extraction of construction quantities and linking these data with public price databases. This integration significantly enhances the efficiency and accuracy of cost estimation, offering a modern solution to challenges faced in traditional methods. However, the study underscores that the success of BIM in this domain depends heavily on the compatibility of BIM models with local budgeting systems, which often vary in structure and requirements. The authors identified key challenges in data transfer from BIM models to price estimation systems, particularly when project documentation is incomplete or inconsistent across different phases of a project. Such inconsistencies hinder the seamless integration of BIM into cost management workflows, limiting its effectiveness. Despite these challenges, two case studies involving motorway projects (D4 and D1) demonstrated the practical advantages of using BIM. The cost estimates generated through BIM were highly accurate, deviating by less than 10% from official estimates, showcasing the technology's potential to deliver reliable financial forecasts for large-scale infrastructure projects. The study concludes that while BIM represents a transformative tool for cost management in transport infrastructure, its full potential can only be realized with further development of compatible software tools and enhanced regulatory frameworks. These advancements would ensure smoother data transfer, better integration with existing budgeting systems, and broader adoption across the industry. By addressing these gaps, BIM can become a cornerstone of efficient and transparent cost management in transport infrastructure projects, fostering greater accuracy and accountability in public spending.

Zou (2019) An extensive analysis examined the development and application of a cost management information system in the construction industry, with a focus on leveraging value-oriented strategies to optimize efficiency and accuracy in project cost management. The study underscores the importance of effective cost control during the design phase, particularly within the context of China's rapid urbanization and the associated growth of its construction sector. It argues that advanced computer and network technologies, when implemented within cost management systems, have the potential to significantly enhance project planning, monitoring, and execution by providing real-time data insights and streamlined processes. However, the research also identifies several critical challenges that hinder the widespread adoption and effectiveness of these systems. China's current cost management practices are described as immature, suffering from a lack of comprehensive data standardization and interoperability between systems. These shortcomings impede the seamless collection, processing, and sharing of project cost data, resulting in fragmented workflows and outdated information. Existing practices, which primarily rely on web-based platforms for data collection, often fail to integrate with intelligent local databases, further exacerbating inefficiencies and inaccuracies in cost estimation and management. Zou highlights the need for a fully integrated project cost management system designed with a value-oriented perspective. Such a system would prioritize the inclusion of key value factors during the design stage, such as life cycle cost estimation and the use of advanced value management techniques. By focusing on these elements, project managers can align project objectives with stakeholder needs, ensure better cost control, and mitigate risks. This integrated approach would not only enhance the accuracy and efficiency of cost management but also contribute to higher quality construction outputs and more sustainable project outcomes. The study concludes that the implementation of a comprehensive cost management system would yield significant benefits for the construction industry. These include improved cost efficiency, reduced risks, and the promotion of sustainable construction practices that align with long-term project success. By integrating advanced technologies and adopting a value-driven strategy, the construction industry can overcome existing challenges and achieve a more streamlined, effective approach to project cost management. This shift would position stakeholders to meet the demands of an increasingly complex and competitive construction environment while contributing to broader goals of sustainability and economic growth.

Kocakaya et al. (2019) conducted a comprehensive study on Building Information Management (BIM) as a revolutionary tool for advancing project management in the construction industry. The research highlights the paradigm shift from traditional project management methods to BIM-enabled integrated systems, which are designed to enhance collaboration among stakeholders, streamline processes, and optimize resource utilization. By adopting BIM, construction projects can achieve significant cost savings, improved efficiency, and better alignment with project timelines and budgets. The study presented a case analysis of a sales-office project, illustrating the practical benefits of BIM in addressing critical challenges. By providing advanced visualization and communication tools, BIM allowed project teams to detect potential construction errors early in the process, mitigating the risk of delays and cost overruns. These findings demonstrate BIM's capacity to create a more proactive project management environment, where issues are identified and resolved before escalating into larger problems. The authors emphasized that BIM plays a crucial role in making construction projects more sustainable and efficient. Its ability to integrate data across various stages of construction facilitates enhanced resource management, improved coordination, and seamless information flow between teams. Additionally, BIM's visualization capabilities provide stakeholders with a clearer understanding of project progress, fostering informed decision-making and minimizing miscommunication. In conclusion, Kocakaya et al. argue that BIM is not just a technological tool but an essential framework for modern construction projects. By enabling better communication, reducing errors, and ensuring resource optimization, BIM supports the delivery of projects that are sustainable, cost-effective, and timely, making it a cornerstone of innovation in the construction industry.

Chepachenko et al. (2020) provided a detailed exploration of the development and application of multiplicative factorial economic models for corporate cost management in the construction sector. The study highlights the critical need for more precise and efficient cost optimization strategies, particularly in the face of intensifying competition, limited resources, and the economic disruptions brought about by the COVID-19 pandemic. These challenges have amplified the demand for innovative approaches to managing costs effectively while maintaining financial stability and competitiveness within the industry. The research focuses on how construction organizations can systematically evaluate the influence of both internal and external factors on material and total costs for production and sales, particularly when incorporating innovative building materials. By employing the expansion method, the authors developed models that enable companies to identify and measure the impact of various factors on cost fluctuations and overall financial outcomes. This methodological approach provides construction organizations with a robust framework for analyzing cost drivers and tailoring their strategies to optimize financial performance.

The study underscores the significance of enhancing the quality of economic analysis in corporate cost management. Accurate and comprehensive analyses equip decision-makers with actionable insights, enabling them to better navigate complex market dynamics and improve operational efficiency. The models proposed by the authors also offer construction organizations the tools to optimize resource allocation, refine cost control mechanisms, and respond more effectively to changing market conditions. These capabilities are essential for fostering greater adaptability and sustainability in an industry facing increasing pressures to innovate and perform in a competitive global economy. Ultimately, Chepachenko et al. conclude that the adoption of these economic models can significantly enhance the competitiveness of construction organizations. By improving their ability to manage costs systematically and adapt to evolving market trends, companies can not only achieve better financial outcomes but also position themselves as leaders in sustainable and efficient construction practices.

Sepasgozar et al. (2022) conducted a comprehensive review exploring the transformative role of Building Information Modeling (BIM) and other digital tools in advancing construction cost management. The study primarily focused on mitigating cost overruns, which represent a critical risk in construction projects. By systematically analyzing 176 scholarly papers, the research categorized the literature into four main clusters: BIM adoption for cost estimation, risk paths, cost control, and virtual design integration. This framework provided an in-depth understanding of current trends and technological innovations in cost management practices. The findings emphasized the remarkable potential of BIM and related digital tools such as CostX and Glodon quantity software in revolutionizing cost estimation accuracy and decision-making processes. These tools enhance data integration across various project phases, promoting transparency and efficiency in managing construction costs. BIM's visualization capabilities allow project teams to simulate design scenarios and detect cost risks at an early stage, enabling proactive adjustments that significantly reduce the likelihood of financial overruns. Furthermore, the seamless integration of virtual design and cost estimation bridges the gap between conceptual planning and execution, optimizing project workflows and minimizing delays.

Despite the progress, the study acknowledged several challenges that hinder the widespread adoption of digital tools in construction cost management. A significant issue is the lack of interoperability among different software platforms, which complicates data sharing and collaborative efforts among stakeholders. Additionally, while the theoretical advantages of digital tools are well-documented, the study highlighted a pressing need for more practical, field-based research to validate their effectiveness in real-world construction environments. The authors concluded by advocating for continued research to refine digital tool applications and overcome existing barriers. Key recommendations included developing universal standards for software interoperability, enhancing professional training programs to build digital competencies, and exploring the integration of emerging technologies such as artificial intelligence and blockchain into cost management frameworks. Addressing these challenges would enable the construction industry to fully harness the potential of digital tools, paving the way for cost-efficient, transparent, and sustainable project delivery.

Li (2018) conducted an in-depth study on the critical challenges and strategies involved in optimizing cost management within China's highly competitive construction market. The research contextualizes the issue within the framework of China's rapid economic growth and international expansion, particularly under the Belt and Road (B&R) initiative, which has heightened competition for local construction firms. As the construction sector faces increasing pressure to deliver quality projects efficiently, the study underscores the pivotal role of effective cost management in ensuring the survival and growth of these companies. The study identifies several persistent issues plaguing current cost management practices in China. These include a lack of awareness regarding market competition, substandard quality control, inadequate time management, and reliance on unscientific cost control approaches. Such deficiencies not only hinder project performance but also diminish the competitiveness of construction firms in an increasingly globalized market. By addressing these issues, construction companies can better adapt to the demands of both local and international projects. To overcome these challenges, Li proposes a series of strategic reforms aimed at transforming cost management practices. Key recommendations include enhancing cost control measures through advanced monitoring systems, integrating quality management techniques to ensure project consistency, and strengthening risk management frameworks to mitigate financial uncertainties. Additionally, the study emphasizes the importance of dynamic cost control systems that can adapt to project complexities and changing market conditions. Employee engagement is also highlighted as a critical factor, with the study advocating for improved training programs to build competencies in cost management and foster a culture of accountability within organizations. Li concludes that comprehensive reforms in cost management practices are essential for construction firms to remain competitive and thrive in both domestic and international markets. By adopting dynamic cost control systems, prioritizing quality and risk management, and fostering employee involvement, construction companies can not only optimize project performance but also align their operations with the demands of a rapidly evolving industry. This strategic alignment will position firms for long-term success in an increasingly interconnected global economy.

Byun and Sohn (2020) introduced ABGS, an innovative system designed to automate the generation of Building Information Models (BIM) from two-dimensional CAD drawings. This development tackles a critical challenge in the construction industry, where reliance on CAD drawings persists despite the well-documented advantages of BIM. The high costs and complexities associated with implementing BIM have hindered its widespread adoption, particularly among small and medium-sized enterprises (SMEs). ABGS seeks to bridge this gap by providing a streamlined and cost-effective solution for transitioning from CAD to BIM. The system works by analyzing both floor plans and member lists within CAD drawings, enabling the generation of BIM models that encompass not only 3D geometric structures but also comprehensive property information.

This dual analysis sets ABGS apart from traditional conversion methods, which often focus solely on floor plan data and result in significant information loss. By preserving detailed property attributes, ABGS ensures the accuracy and integrity of the BIM models, making them more practical for a wide range of applications in construction planning and management. Experiments conducted with ABGS demonstrated its ability to convert CAD drawings into Industry Foundation Classes (IFC) files quickly and accurately. The system was tested on real architectural projects, showcasing its potential to simplify the BIM adoption process. This capability is particularly beneficial for SMEs, as it reduces the technical and financial barriers to leveraging BIM technology. By enabling a seamless transition from CAD to BIM, ABGS not only facilitates improved design and collaboration but also supports the broader digital transformation of the construction industry.

The authors emphasized that the efficiency and precision of ABGS make it a promising tool for accelerating BIM integration, addressing a critical bottleneck in modern construction workflows. The system's ability to make BIM more accessible aligns with industry trends towards greater digitalization and efficiency, offering a practical pathway for firms to enhance their operations and competitiveness in an evolving market.

2.5. Comparison between 2D AutoCAD and BIM:

Cus Babic and Rebolj (2016) conducted a pivotal study addressing the cultural transformation necessary for the construction industry's shift from traditional 2D paper-based workflows to Building Information Modeling (BIM) methods. While the technological and operational advantages of BIM are well-established, the authors emphasize that its adoption has been slower than expected, largely due to entrenched institutional and cultural norms within the architecture, engineering, and construction (AEC) sector. Their research employs Institutional Theory to explore the persistence of 2D practices, shedding light on the regulatory, normative, and cognitive-cultural factors that uphold these traditional workflows. The study reveals that the construction industry’s reliance on 2D drawings for critical functions such as communication, contract documentation, and regulatory compliance has created a deeply ingrained system resistant to change. These practices, long institutionalized, provide a sense of stability and predictability that deters organizations from adopting more dynamic but unfamiliar BIM-based processes. Regulatory frameworks often reinforce this reliance on 2D documentation, while normative pressures from within the industry perpetuate the use of established workflows. Additionally, cognitive-cultural beliefs about the effectiveness and familiarity of 2D methods further impede the transition to BIM, despite its proven benefits. Cus Babic and Rebolj argue that overcoming this resistance requires more than just technical training and software implementation. A fundamental cultural shift is necessary—one that redefines industry norms, challenges outdated regulatory requirements, and fosters an environment supportive of innovation and collaboration. The authors highlight the importance of addressing organizational structures and social dynamics, as these factors are critical for enabling the adoption of new technologies. This cultural transformation must also involve stakeholders across all levels of the industry, ensuring that the transition to BIM is not seen merely as a technological upgrade but as a holistic change in the way construction projects are designed, managed, and executed. The study concludes that the full integration of BIM into the AEC sector requires a multifaceted approach, combining technical advancements with targeted efforts to shift cultural and institutional mindsets. By addressing these broader social and organizational challenges, the construction industry can unlock the full potential of BIM, leading to greater efficiency, innovation, and sustainability in future projects.

Juninawan et al. (2023) conducted a detailed investigation into the application of automation in AutoCAD-based building component drawings, emphasizing its impact on time efficiency and accuracy in construction planning. The study focused on enhancing traditional AutoCAD® workflows by introducing automation through NET C# programming. This approach replaces the standard one-command-per-object syntax with a more advanced methodology, where a single command generates multiple outcomes, streamlining the drawing process. The research adopted a quantitative comparative design to evaluate the effectiveness of the usual command (UC) method versus the automatic command (AC) method. Paired samples involving 10 respondents were analyzed to measure improvements in time efficiency and drawing accuracy. The findings revealed significant enhancements in both metrics when using the AC method. Automation enabled the respondents to complete complex drawing tasks, such as reinforced concrete details, foundation designs, and roof structures, in considerably less time compared to traditional methods, while maintaining high precision. The automation system developed by the authors was rigorously tested on a variety of building components, showcasing its versatility and reliability in practical scenarios. By automating repetitive and time-consuming tasks, the system reduced the workload on drafters and minimized human errors, leading to a notable improvement in overall project planning and execution. The authors highlighted that this innovation not only speeds up the drawing process but also ensures consistency and accuracy across all project documentation. Juninawan et al. concluded that incorporating automation into AutoCAD workflows represents a transformative step for the construction industry. By enhancing efficiency and precision, automated drawing processes contribute to more effective project management and better resource allocation. This advancement supports the broader trend of digitalization in construction, demonstrating how automation technologies can address critical challenges in planning and execution, ultimately leading to improved project outcomes.

Kashlev (2008) introduced an innovative system named 3dGen, designed to convert 2D floor plans into 3D building models to enhance visualization and identify design inconsistencies in architectural projects. This system utilizes XML data extracted from AutoCAD drawings to create detailed 3D representations by extruding walls and vertical surfaces and integrating essential three-dimensional information. The 3dGen system significantly improves upon traditional methods by ensuring watertight spaces, which are critical for accurate modeling, and minimizing redundant geometric data through the elimination of duplicate geometric primitives. The research delves into the technical specifics of the system, offering detailed algorithms for generating precise surfaces and handling a variety of architectural features, such as portals and openings. These algorithms not only facilitate the creation of accurate 3D models but also enable the system to detect inconsistencies in the original 2D plans. By addressing potential design flaws early in the planning phase, the system helps reduce errors that could escalate during construction. One of the most notable advantages of 3dGen is its ability to enhance communication between architects and clients. By providing a clear and realistic visualization of indoor spaces, the system enables clients to better understand the spatial relationships and aesthetic aspects of the design. This improved clarity fosters more informed decision-making and aligns client expectations with architectural outcomes. Kashlev emphasizes that the 3dGen system represents a significant step forward in architectural modeling, combining technical efficiency with practical usability. By bridging the gap between 2D plans and 3D visualizations, 3dGen not only streamlines the design process but also contributes to better project outcomes by reducing errors, enhancing collaboration, and supporting more accurate and efficient design practices.

Barki et al. (2015) conducted an in-depth study on the generation of Building Information Modeling (BIM) systems from 2D CAD drawings and 3D laser scans, with a particular emphasis on their application to existing structures. The research focused on reconstructing BIM models for emergency preparedness in a high-rise tower in Qatar, providing valuable insights into the challenges and opportunities of transitioning from traditional CAD-based workflows to fully integrated BIM systems. The study highlighted several limitations associated with CAD-to-BIM conversions, such as the lack of data integration, inefficiencies in workflows, and the time-intensive nature of manual data processing. Advanced 3D capture techniques, including laser scanning and photogrammetry, were presented as solutions to these challenges, offering higher levels of detail and accuracy. By combining laser scans with traditional CAD data, the authors demonstrated how a hybrid approach could address discrepancies in older building data and facilitate the creation of accurate and comprehensive BIM models.

Using a case study of a high-rise tower, the research illustrated the complexities of integrating outdated CAD drawings with updated 3D scans. These challenges included handling incomplete or inconsistent data, managing large data sets, and ensuring interoperability between various software platforms. Despite these hurdles, the study emphasized the potential of automation in streamlining the BIM generation process. Automated tools can bridge the gap between CAD and BIM workflows, enabling faster and more efficient model creation while maintaining high levels of accuracy. Barki et al. concluded that while significant progress has been made in CAD-to-BIM and Capture-to-BIM methodologies, further research is needed to refine these processes. Streamlining these workflows is essential for integrating older buildings into modern BIM systems, which is increasingly important for applications like emergency preparedness, facility management, and sustainable retrofitting. The study underscores the transformative potential of combining advanced 3D capture technologies with BIM, paving the way for more efficient and accurate modeling practices in the construction and facilities management industries.

Su et al. (2013) introduced an innovative solution to address inefficiencies in shop drawing management through the development of a BIM-based Shop Drawing Automated (BSDA) system. This system integrates Building Information Modeling (BIM) with 2D barcode technology, creating a streamlined process for managing and accessing shop drawings during the construction phase. The study identified key challenges associated with traditional 2D shop drawings, particularly the time-consuming and error-prone task of locating specific drawings on-site. The BSDA system offers a modernized alternative, enabling seamless access to BIM models linked directly to shop drawings. The core functionality of the BSDA system lies in its integration of 2D barcodes with BIM models. Each shop drawing is associated with a unique 2D barcode that can be scanned using a mobile device or barcode scanner. By scanning the barcode, on-site engineers can instantly access the corresponding 3D BIM model, ensuring they have immediate access to the most up-to-date information. This feature eliminates delays caused by manual searches for drawings, enhances communication between teams, and reduces the risk of errors associated with outdated or misplaced documents. The system was implemented and tested in a real-world construction project in Taiwan, demonstrating its practical benefits. The results showed that the BSDA system significantly improved the efficiency of construction processes by enabling faster access to BIM models and ensuring that the latest versions of shop drawings were always accessible. Moreover, the system enhanced communication between project stakeholders by providing a centralized and easily navigable repository of construction documentation. They concluded that the BSDA system represents a substantial advancement in shop drawing management within a BIM environment. By combining BIM's visualization capabilities with the simplicity of 2D barcodes, the system streamlines project management and communication during the construction phase. This integration not only saves time and reduces errors but also fosters a more collaborative and efficient construction workflow. The study underscores the potential for similar technological innovations to further enhance construction management practices.

Barreiro, A. C., Trzeciakiewicz, M., Hilsmann, A., and Eisert, P. (2023) conducted a study on the automatic reconstruction of semantic 3D models from 2D floor plans, introducing a pipeline that significantly enhances the efficiency and accuracy of building digitalization. The research addresses a persistent challenge in the construction industry: older buildings often lack digital floor plans or semantic data, necessitating labor-intensive and error-prone manual reconstruction processes. Leveraging advanced deep learning techniques, particularly convolutional neural networks (CNNs), the study automates critical tasks such as wall segmentation and symbol detection for architectural components like doors and windows. This automation not only reduces manual effort but also ensures a higher level of precision and consistency in the resulting 3D models. The methodology achieves state-of-the-art results on the CubiCasa5k dataset, outperforming existing approaches, particularly in vectorization tasks where its accuracy and efficiency are unparalleled. The reconstructed 3D models are compatible with Industry Foundation Classes (IFC), facilitating seamless integration with widely used CAD tools. This compatibility streamlines workflows across building design, construction, and maintenance phases, ensuring practical applicability in real-world scenarios. Furthermore, the pipeline demonstrates a high degree of versatility, effectively reconstructing diverse types of floor plans, including those for residential and office buildings. By addressing the limitations of traditional manual methods, the study sets a new standard for the digitalization of building data, contributing significantly to the modernization of building lifecycle management practices. They conclude that their pipeline represents a transformative advancement in the automation of 3D model generation, offering solutions that align with the growing demand for digitalization in construction. This innovation not only improves design and construction efficiency but also supports sustainable building management by providing a reliable foundation for planning, execution, and long-term maintenance activities. The study underscores the potential for further advancements in integrating automation with construction technologies, paving the way for smarter and more connected infrastructure.

Ibrahim et al. (2019) investigated the integration of Building Information Modeling (BIM) with robotic automation to enhance indoor construction progress tracking, introducing a BIM-driven mission planning and navigation system. The research presents a groundbreaking pipeline that combines 4D BIM models with an Unmanned Ground Vehicle (UGV) equipped with 2D Light Detection and Ranging (LiDAR) sensors, employing simultaneous localization and mapping (SLAM) technology. This innovative system addresses key challenges in construction progress reporting, such as poor Global Navigation Satellite System (GNSS) signals in indoor environments and the high costs and inefficiencies associated with manual data collection. By automating navigation and data acquisition, the study provides a robust solution for monitoring construction progress in real-time. The authors demonstrated that the UGV effectively navigates complex indoor spaces, overcoming obstacles and adapting to dynamic changes in its environment. The integration of SLAM technology allows for precise localization, enabling the UGV to generate accurate 3D reconstructions of the as-built conditions and seamlessly compare them to 4D BIM models. This automated approach reduces reliance on manual labor, accelerates data collection, and minimizes errors in progress tracking. Additionally, the system enhances the visibility of construction progress, enabling stakeholders to make informed decisions and maintain project timelines more effectively. The study concludes that BIM-driven robotic platforms represent a transformative advancement in construction progress tracking, offering significant improvements in speed, accuracy, and cost-efficiency. By leveraging autonomous navigation and advanced data collection technologies, this approach enhances the overall management of construction projects, particularly in challenging indoor environments. The findings underscore the potential for further integration of robotics and BIM to optimize construction workflows, paving the way for smarter, more automated building processes.

2.6 Challenges and Barriers to BIM Adoption:

Kushwaha (2016) conducted an in-depth exploration of the transformative role of Building Information Modeling (BIM) in addressing persistent challenges within the Architecture, Engineering, and Construction (AEC) industry. The study emphasizes BIM's ability to foster collaboration by providing real-time access to project data for all stakeholders. This enhanced communication and coordination significantly improve the management and execution of construction projects, ensuring greater alignment among diverse teams. Through its multidimensional capabilities—ranging from 3D modeling to 4D (time), 5D (cost), and 6D (sustainability)—BIM is presented as a tool that revolutionizes project management. It facilitates advanced visualization, allowing stakeholders to foresee and address potential issues, supports precise cost estimation to optimize financial resources, and promotes sustainable practices that align with modern environmental standards. The research also delves into the barriers that hinder widespread BIM adoption. Key challenges include a shortage of skilled professionals equipped to work with BIM technologies, the high initial investment required for implementation, and a general resistance to adopting new methods, particularly in small-scale projects. These obstacles often limit the accessibility and perceived feasibility of BIM, despite its demonstrated advantages in improving project outcomes. Kushwaha concludes that, while these challenges persist, BIM is undeniably a game-changer for the AEC industry. By reducing project costs, enhancing delivery timelines, and elevating overall quality, BIM offers substantial value to construction processes. The study underscores the importance of targeted interventions, such as comprehensive education and training programs, along with supportive policies and incentives from governments, to facilitate the broader adoption of BIM across projects of varying scales. These steps are critical to unlocking the full potential of BIM, ensuring it becomes a standard practice in advancing the efficiency and sustainability of the construction industry.

Svetel et al. (2014) conducted a comprehensive analysis of the potential and limitations of Building Information Modeling (BIM) technology, examining its capacity to transform the architecture, engineering, and construction (AEC) industry. The study underscores BIM's promise as a tool for enhancing collaboration among stakeholders by providing a unified digital platform for project data. By leveraging technologies such as Industry Foundation Classes (IFC) and Building SMART Data Dictionary (BSDD), BIM facilitates interoperability between diverse applications, enabling more cohesive workflows and reducing silos within construction projects. These open standards play a pivotal role in ensuring that project data can be effectively shared and utilized across various teams and software systems. Despite these advancements, the authors identify several barriers that have hindered BIM's widespread adoption. Challenges include issues of data ownership and the assignment of responsibility for maintaining the accuracy of shared information. Furthermore, the study highlights the complexity and cost of implementing BIM, particularly for smaller firms that often lack the necessary resources to adopt and integrate such technologies into their operations. These barriers limit the accessibility of BIM and contribute to its slower-than-expected adoption within the AEC industry. The authors conclude that while BIM offers transformative potential, it is not a universal solution for all projects or organizations. Successful integration of BIM requires tailored strategies, significant investment in training, and a willingness to adapt existing workflows. The study emphasizes that for smaller organizations to benefit from BIM, industry stakeholders and policymakers must work to lower entry barriers through initiatives such as funding support, simplified tools, and targeted education programs. Without such efforts, the full promise of BIM may remain unrealized, particularly for firms operating on limited budgets or with minimal technical expertise.

Afsari, K., Florez, L., Maneke, E., and Afkhamiaghda, M. (2019) investigated the integration of smart building components within Building Information Modeling (BIM), focusing on the challenges and opportunities of embedding dynamic elements such as sensors, actuators, and microprocessors into BIM models. Their research highlights the complexity of representing the real-time nature of smart components, which continuously interact with their environment and influence design and construction decisions in smart building projects. By categorizing smart components across key building disciplines—architectural, structural, mechanical, electrical, and fire protection—the study demonstrates a holistic approach to modeling smart spaces. Through their experiment, the authors modeled nine smart components in a simulated environment and developed equations to represent their dynamic behaviors within BIM models. This simulation-driven approach ensures that real-time data from smart components can be effectively represented, enabling more accurate and informed decision-making during construction and beyond. The research also underscores a significant limitation of current BIM tools, which remain predominantly static and require extensive manual data entry to account for the dynamic nature of smart components. This constraint highlights the need for BIM systems to evolve to accommodate simulation and real-time data integration for effective modeling of smart buildings. The study concludes that while current BIM tools provide a strong foundation for construction and design, they must advance to include simulation-driven capabilities that dynamically integrate smart component data. The authors emphasize the importance of future research focused on enhancing BIM systems to support the lifecycle management of smart buildings. Such advancements would improve facility management, enhance operational efficiency, and drive the performance of smart buildings by leveraging real-time data integration and dynamic modeling capabilities.

Glema (2017) explored the transformative potential of Building Information Modeling (BIM) as a pivotal element in the digital evolution of the construction industry, with a particular focus on its implementation in Poland. The study underscores BIM's capacity to revolutionize project management by integrating advanced digital tools such as cloud computing, augmented reality (AR), and virtual reality (VR). These technologies collectively enable a more efficient and risk-averse approach to managing the entire lifecycle of construction projects, from initial design to final execution and maintenance. Glema highlights how BIM facilitates a "virtual build" as the starting point for the digital construction process, allowing stakeholders to simulate various project scenarios, optimize resource allocation, and identify potential issues before physical construction begins. This capability significantly enhances decision-making and reduces costly errors and delays. The research also sheds light on the barriers to BIM adoption in Poland, particularly the challenges posed by the existing legal and regulatory frameworks, as well as the lack of widespread acceptance across the construction sector. These issues, coupled with limited awareness and technical expertise, slow down the industry's transition to fully digitalized workflows. Despite these challenges, Glema argues that the growing global emphasis on digital construction methods, supported by BIM, represents a necessary shift for Poland's construction industry to remain competitive and address emerging demands. By examining technological advancements and future trends, the study concludes that BIM-driven digital construction methods are essential for tackling the complex challenges of modern construction projects. Glema emphasizes the need for comprehensive policy reforms, industry-wide collaboration, and investment in education and training to ensure the successful integration of BIM and other digital tools. The paper positions BIM not only as a tool for improving efficiency and reducing risks but as a critical enabler of innovation and sustainability in the evolving construction landscape.

Gray et al. (2012) conducted a comprehensive international survey to evaluate the adoption and transformative impact of Building Information Modeling (BIM) within the architecture, engineering, and construction (AEC) industry across multiple countries. Their study underscores the growing significance of BIM as a critical tool for enhancing project delivery by improving collaboration among stakeholders, facilitating advanced visualization, and enabling efficient management of building data throughout the construction lifecycle. The survey revealed distinct patterns in BIM adoption, highlighting its varied usage across different disciplines, project stages, and levels of technology integration. These patterns reflect how BIM is tailored to meet the unique requirements of diverse projects, from early design phases to post-construction management. The authors also delved into the challenges hindering the broader adoption of BIM. Key barriers include issues of software interoperability, which complicate data sharing across platforms; difficulties in managing the vast amounts of data generated by BIM systems; and legal concerns such as intellectual property rights and data ownership. These obstacles underscore the need for cohesive strategies to streamline the integration of BIM technologies into existing workflows. The study concludes that while BIM offers transformative potential for the AEC industry, its widespread adoption depends on addressing both technical and organizational challenges. The development of standardized industry practices, regulatory frameworks, and comprehensive training programs is vital to unlocking BIM's full capabilities. Their research emphasizes that fostering collaboration and establishing clear guidelines for BIM use will be critical to achieving its promise of revolutionizing project delivery and efficiency in the global construction sector.

Azhar (2011) explored the trends, benefits, risks, and challenges of Building Information Modeling (BIM) within the architecture, engineering, and construction (AEC) industry, presenting a detailed analysis of its transformative potential. The study emphasizes BIM's ability to revolutionize construction practices through the creation of accurate virtual models, which serve as comprehensive tools for planning, design, construction, and facility operation. By integrating detailed digital representations of buildings, BIM facilitates enhanced collaboration among stakeholders, enabling better communication and decision-making throughout the project lifecycle.

The research highlights the notable advantages of BIM, including reduced project costs, improved productivity, and faster project delivery. These benefits stem from the technology's capacity to streamline processes, minimize errors, and optimize resource allocation. Additionally, the study points to BIM's role in improving project outcomes by enabling more accurate visualizations, clash detections, and real-time updates, which collectively contribute to smoother execution and better alignment with project objectives. However, the study does not shy away from addressing the risks and challenges associated with BIM adoption. Among the most pressing issues are legal and technical hurdles, such as questions of data ownership, software interoperability, and the lack of industry-wide standards for implementation. These challenges are compounded by resistance to change within the industry and the high costs associated with initial adoption and training. The study concludes that while BIM offers significant opportunities for innovation and efficiency in the AEC sector, its widespread adoption will depend on overcoming these barriers. The authors advocate for the development of standardized implementation practices and proactive strategies to address legal and technical risks early in the project lifecycle, ensuring that BIM's potential can be fully realized across the industry.

Moller and Bansler (2017) examined the role of Building Information Modeling (BIM) in enhancing collaboration in large-scale construction projects, focusing specifically on a hospital construction project in Denmark. Their research highlights BIM's transformative potential as a tool for achieving "perfect information" by integrating diverse inputs from architects, engineers, and future users into a unified digital model. This integration facilitates better decision-making, allowing for more efficient and effective project execution. The study identifies three essential types of design reviews enabled by BIM: clash detection, scenario-based reviews, and embodied reviews. Each of these processes addresses critical aspects of the conceptual design phase, from identifying and resolving conflicts between building systems to visualizing and simulating user interactions with the design. The findings emphasize that BIM significantly improves collaboration among stakeholders by fostering transparency and real-time communication. By streamlining the flow of information, BIM helps ensure that all participants are aligned with the project's goals and constraints, reducing errors and delays. However, the study also points out the challenges of implementing BIM in such complex projects. The integration of input from various specialists, each with unique priorities and expertise, often leads to complications that require substantial coordination and adaptation. The authors conclude that while BIM has the potential to revolutionize collaboration and efficiency in the construction industry, its successful application depends on ongoing refinement of processes and technologies. Continuous effort is required to overcome technical and organizational challenges, ensuring that BIM can fulfill its promise as a unified platform for large-scale, collaborative construction projects.

Azhar et al. (2012) provided a detailed examination of Building Information Modeling (BIM), highlighting its transformative potential within the architecture, engineering, and construction (AEC) industry. The study positions BIM as both a technology and a process, emphasizing its capacity to integrate digital information seamlessly across a building's lifecycle. This integration facilitates enhanced collaboration, cost reduction, and more efficient project delivery by streamlining communication and ensuring that all stakeholders operate from a unified, accurate model. The authors underscore BIM’s ability to improve decision-making, enhance project coordination, and support sustainability through advanced design and resource management capabilities. The research outlines several significant benefits associated with BIM. These include its capacity to provide real-time updates, detect clashes between building systems, and simulate various scenarios, all of which contribute to better project outcomes. Furthermore, BIM's emphasis on data-rich models enables a more comprehensive approach to sustainability, ensuring that projects align with environmental goals while optimizing cost efficiency. Despite these advantages, the authors identify multiple barriers that hinder BIM's widespread adoption. Interoperability issues between different software platforms create challenges in data sharing and collaboration. Additionally, the high costs associated with implementing BIM systems, coupled with legal uncertainties regarding data ownership and responsibility, pose significant obstacles. The lack of standardized practices and resistance to change within the industry further complicates its integration into traditional workflows. The study concludes that while BIM holds immense potential to revolutionize the AEC industry, achieving this transformation requires addressing both technological and procedural challenges. The authors advocate for greater industry collaboration, development of standardized protocols, and efforts to lower the cost and complexity of BIM adoption, paving the way for its more extensive implementation and success.

2.7. Advanced Applications of BIM and Digital Tools:

Salem and Dragomir (2022) conducted an extensive analysis of digital twins' applications and challenges in construction management, highlighting their transformative potential in enhancing project oversight, cost control, and decision-making. Digital twins are presented as dynamic systems that replicate physical assets digitally by continuously integrating data from real-time sensors and simulations. This capability allows for real-time monitoring and analysis of construction projects, enabling managers to predict issues, optimize workflows, and make informed decisions. The study categorizes the development of digital twins into three progressive stages: Building Information Modeling (BIM) as the foundational stage, monitoring digital twins that integrate real-time data, and a future stage leveraging advanced artificial intelligence. These stages illustrate the evolution of digital twins from static models to intelligent systems capable of predictive analytics. By bridging the gap between the physical and digital worlds, digital twins can significantly reduce budget overruns, improve worker safety, and streamline project timelines, making them a vital tool in modern construction management. However, the authors acknowledge several challenges that hinder the widespread adoption of digital twins. Among these are the lack of standardized frameworks for implementation, cybersecurity concerns related to the integration of sensitive data, and the complexity of aligning technologies such as IoT and machine learning. Organizational resistance and regulatory hurdles also present significant barriers, particularly in industries where traditional processes remain deeply entrenched. The study concludes that while digital twins hold immense promise for revolutionizing construction management, their successful implementation requires coordinated efforts to address these challenges. Developing industry standards, enhancing cybersecurity protocols, and fostering interdisciplinary collaboration are critical steps toward realizing the full potential of digital twins. By overcoming these barriers, digital twins can lead to more efficient, cost-effective, and safer construction projects.

Chen et al. (2018) conducted an insightful investigation into the integration of Building Information Modeling (BIM) and robotic technology, focusing on their combined potential to address critical challenges in the construction industry. The study sheds light on persistent issues such as inaccuracies in component placement, inefficiencies in managing large-scale projects, and the limitations of traditional human-driven processes. BIM, while transformative in enhancing visualization and coordination, has inherent limitations in ensuring precise execution on-site, particularly in projects involving multiple stakeholders and complex systems. By pairing BIM with intelligent robotic systems, the research demonstrated significant advancements in construction processes. Intelligent robots were utilized to align on-site construction activities with BIM-generated digital models, enabling precise component positioning and minimizing human error. The study showcased practical applications in ceiling installations, underground pipeline projects, and bridge construction. In these cases, robotic systems guided by BIM models not only improved accuracy but also streamlined workflows, reducing project delays and enhancing overall efficiency. The integration of robotics with BIM also allowed for real-time monitoring and adjustments, ensuring that the physical construction adhered closely to digital designs. This alignment improved quality control, reduced material wastage, and optimized resource utilization, providing substantial cost savings. Additionally, the use of robots alleviated physical strain on workers and enhanced safety by automating tasks in hazardous environments. The authors conclude that the synergy between BIM and robotic technology has the potential to revolutionize construction practices. However, they emphasize the need for continued research and development to address challenges such as high implementation costs, training requirements, and the need for seamless interoperability between BIM software and robotic systems. With these advancements, BIM-robot integration could set new standards in construction management, ensuring projects are delivered with unparalleled precision, efficiency, and control over quality, cost, and time.

Vycital and Jarský (2020) conducted an in-depth study on the integration of the CONTEC method with Building Information Modeling (BIM) to automate the creation of nD models, addressing the growing need for efficient and dynamic construction management systems. The research highlights the potential of combining BIM's comprehensive data management capabilities with CONTEC's advanced modeling techniques to generate discrete nD models, covering dimensions beyond the conventional 3D. These dimensions include 4D for scheduling, 5D for budgeting, 6D for health and safety, 7D for quality assurance, and 8D for environmental planning. The methodology was tested through a case study involving an office building, where the integration of BIM and CONTEC automated the creation of nD models reflecting actual construction timelines and costs. The study demonstrated how this approach streamlines the construction process by automating complex tasks that typically require significant manual effort, such as linking schedules to physical components (4D) or aligning budgets with material specifications (5D). Additionally, the generated models incorporated critical parameters for safety compliance, quality management, and environmental impact, creating a holistic system for project oversight.

Findings from the case study reveal that the integration of CONTEC and BIM significantly enhances efficiency by reducing the time and errors associated with manual data entry and model updates. This automation not only ensures consistency and accuracy across various construction phases but also provides project managers with a cohesive framework for decision-making. By interlinking diverse datasets into a single BIM environment, the approach facilitates better planning, resource allocation, and compliance monitoring. The authors conclude that the CONTEC method represents a promising advancement in expanding the capabilities of BIM, offering substantial benefits for construction planning and execution. However, they also underscore the importance of developing standardized protocols and ensuring interoperability between BIM platforms and specialized software like CONTEC. With further refinement and adoption, this integrated approach could revolutionize how nD modeling is utilized in modern construction, paving the way for more sustainable, efficient, and safe construction practices.

Arias et al. (2022) investigated the integration of Constraint Logic Programming (CLP) with Building Information Modeling (BIM) to address critical gaps in compliance checking within the architecture, engineering, and construction (AEC) industry. Their research emphasizes the limitations of current BIM tools, which struggle to adapt to varying regulatory requirements and dynamic updates in building models. To overcome these issues, the authors proposed leveraging advanced logic-based systems such as CLP and Constraint Answer Set Programming (CASP). These systems unify the representation of both geometrical and non-geometrical information within BIM models, providing a flexible and comprehensive framework for reasoning about building compliance. The study introduced a prototype reasoner built using CLP(Q/R) and CASP, capable of managing complex scenarios such as ambiguous data, incomplete information, and iterative changes to building designs. By integrating these tools, the authors demonstrated improved efficiency in rule compliance checks, reducing the likelihood of costly design revisions. Through their experiments, the researchers highlighted the potential for this approach to streamline the compliance verification process, ensuring that building projects meet regulatory standards without significant delays. The findings suggest that the integration of CLP with BIM offers a transformative methodology for refining BIM models and improving compliance verification in construction projects. This approach not only enhances the accuracy of compliance checks but also contributes to more sustainable and cost-effective project management practices by minimizing errors and rework. The study underscores the need for further research and development to scale this methodology for broader adoption within the AEC industry.

Tyurin (2020) investigated the automation of identifying construction work and structural elements within the framework of Building Information Modeling (BIM). The study highlights the transition from traditional design systems, which predominantly relied on manual drafting and 2D drawings, to advanced information modeling technologies (IMT) that deliver enhanced detail, precision, and efficiency in construction and design workflows. The research underscores the transformative potential of automating design tasks through BIM, particularly in detailing complex construction elements and facilitating resource estimation. The proposed methodology introduces a systematic approach that leverages databases of pre-designed elements to automate repetitive design tasks, such as selecting sanitary points or assigning attributes to structural components. By incorporating advanced computational tools like suffix arrays and fuzzy logic, the methodology enables the automated identification and calculation of construction elements, minimizing human intervention. This automation significantly reduces manual errors and expedites the overall design and modeling process. The research demonstrates how these automated processes can achieve a higher level of detail in BIM models, particularly in resource calculation and structural detailing, thus enhancing the reliability and efficiency of the construction workflow. Tyurin concludes that adopting this automated framework will not only improve the accuracy of BIM models but also streamline project workflows and elevate the standard of construction project management. By reducing manual effort and increasing precision, the methodology supports more efficient decision-making, resource allocation, and project execution, aligning with the industry's growing demand for digital transformation in construction processes.

Pandya and Koehn (2009) explored the transformative relationship between Building Information Modeling (BIM) and sustainability, shedding light on BIM's pivotal role in advancing sustainable design and enhancing building performance. The study emphasizes that BIM, as a digital framework, facilitates the creation of coordinated and computable data models, which can be effectively utilized across multiple disciplines, project phases, and by diverse stakeholders. This capability ensures that sustainability considerations are embedded seamlessly throughout the building lifecycle, from conceptual design to operation and maintenance. The research underscores BIM’s unique ability to support key sustainable design principles, including optimizing energy consumption, improving water conservation strategies, and enhancing indoor environmental quality. By enabling advanced simulation and analysis, BIM allows for detailed assessments of building performance, helping design teams to identify inefficiencies and implement solutions early in the planning phase. These insights contribute significantly to reducing greenhouse gas emissions and ensuring the overall environmental responsibility of construction projects. Moreover, the authors discuss the role of BIM in aligning with established sustainability frameworks, particularly the Leadership in Energy and Environmental Design (LEED) certification process. BIM simplifies the complex documentation required for LEED certification by providing comprehensive data models that streamline compliance checks and facilitate accurate reporting. This alignment not only accelerates the certification process but also ensures that sustainable practices are prioritized without compromising project timelines or costs. The study highlights how BIM fosters collaboration among architects, engineers, and sustainability consultants by providing a centralized platform for sharing data and making informed decisions. This integration minimizes errors, reduces resource wastage, and enhances project efficiency. By simulating the performance of various design alternatives, BIM empowers stakeholders to choose solutions that align with environmental goals and deliver long-term economic benefits. Pandya and Koehn also identify BIM's potential to redefine green building practices by enabling lifecycle assessments that extend beyond construction. By modeling energy use, material impacts, and operational performance, BIM ensures that buildings not only meet but exceed sustainability benchmarks. The authors advocate for broader adoption of BIM, highlighting its ability to address pressing global challenges such as resource scarcity and climate change. In conclusion, the study establishes BIM as a cornerstone for sustainable construction, emphasizing that its integration with frameworks like LEED marks a significant advancement in green building methodologies. The authors argue that BIM's potential goes beyond immediate cost savings and performance improvements; it represents a paradigm shift in how the construction industry approaches environmental stewardship. As the demand for sustainable construction grows, BIM's role in facilitating transparent, efficient, and eco-conscious building practices becomes increasingly indispensable. This intersection of technology and sustainability provides a roadmap for the construction industry to achieve greater environmental, economic, and social impact in the years to come.

Çıdık and Boyd (2022) investigated the profound value implications of digital transformation within the construction sector, with a particular emphasis on its impact on coordination practices through the commodification of information. Their study delves into how digitalization reshapes traditional value creation frameworks by prioritizing the production value creation logic—centered on standardizing and formalizing processes—over project-specific coordination practices that rely on social mutual adjustment. This shift is critically analyzed within the dual frameworks of production and project value creation, revealing how digital tools and processes enhance efficiency and integration but potentially undermine the flexibility needed for project-specific collaboration. The authors argue that digital transformation in construction reframes information as a commodity, elevating its digital exchange value—how information is traded or shared—above its practical use value, which pertains to its applicability and relevance within specific project contexts. This commodification introduces new dynamics in how value is created, captured, and coordinated among stakeholders, potentially leading to imbalances where rigid formalization hinders the adaptability required for unique project conditions. While acknowledging the operational benefits brought by digitalization, such as improved process integration and streamlined workflows, the study highlights significant challenges. These include political and economic implications, such as power asymmetries among stakeholders, and the risk of prioritizing standardized digital solutions at the expense of tailored, context-sensitive approaches. The authors argue that this imbalance could impact collaboration, innovation, and the overall success of projects. The study concludes with a call to action for policymakers, industry leaders, and construction managers to critically assess and address these challenges. By recognizing the dual nature of value creation logics, stakeholders can devise strategies that balance the benefits of digitalization with the need for project-specific flexibility. This approach would ensure that digital transformation in construction not only enhances efficiency but also sustains the social and collaborative elements essential for successful project delivery. The authors underscore the importance of fostering a nuanced understanding of how digital tools influence the socio-economic fabric of construction projects, advocating for policies and practices that harmonize production and project value creation.

Lee et al. (2015) carried out a detailed investigation into the quantitative analysis of warnings in Building Information Modeling (BIM), focusing on the impact of warning management on improving model processing efficiency in large construction projects. Using data collected from three extensive healthcare projects in California, the study employed Pareto analysis to identify and categorize warning types and their frequencies. Their findings demonstrated that approximately 15% of warning types were responsible for nearly 80% of the total warnings, validating the 15-80 principle in the context of BIM design processes. This insight highlights the importance of addressing a relatively small subset of recurring issues to significantly enhance model efficiency. The research also revealed that warning patterns varied across different design phases, with the schematic design phase exhibiting distinct characteristics. During this phase, about 25% of warning messages accounted for 80% of all warnings, underscoring the need for targeted management strategies tailored to specific stages of the design lifecycle. To further address these challenges, the authors proposed time estimation methods for resolving warnings, grounded in learning curve theory. These methods provide a framework for estimating the time required to address recurring warnings, enabling teams to allocate resources effectively and avoid delays. By emphasizing the efficient management of BIM warnings, the study highlights their critical role in reducing processing delays, mitigating bloated file sizes, and ensuring smooth project workflows. The research concludes that proactive warning management is essential for optimizing BIM design processes, particularly in large and complex projects where inefficiencies can compound rapidly. These findings offer valuable guidance for practitioners seeking to enhance design management practices and improve overall project outcomes in the construction industry.

Seyman-Güray and Kısmet (2022) investigated the incorporation of 4D and 5D modeling into construction management education for architecture students, proposing a comprehensive digitalization framework aligned with the transformative goals of Construction 4.0. Their study focused on equipping students with essential skills in time and cost management by integrating advanced technologies such as Building Information Modeling (BIM), Augmented Reality (AR), and Virtual Reality (VR) into a "Construction Management and Economics" course. The framework was designed to bridge the gap between theoretical knowledge and practical application, addressing the Architecture, Engineering, and Construction (AEC) industry's growing reliance on digital tools for effective project management. By leveraging 4D modeling to simulate construction timelines and 5D modeling for cost estimation, the framework enabled students to visualize construction sequences, identify potential clashes, and accurately estimate project costs. This hands-on approach not only enhanced their comprehension of complex construction processes but also improved their decision-making and analytical skills in managing project constraints. The course provided students with a virtual environment to experiment with real-world scenarios, fostering a deeper understanding of how time and cost variables influence project outcomes.

Feedback from a survey conducted among students who participated in the course indicated that the digitalization framework significantly enhanced their learning experience. Students reported a stronger grasp of construction management concepts, improved confidence in using advanced digital tools, and a better understanding of how these technologies are applied in professional contexts. The authors concluded that integrating 4D and 5D modeling into educational programs is crucial for preparing future professionals to meet the AEC industry's evolving demands. Additionally, this approach underscores the importance of aligning academic curricula with technological advancements to ensure that graduates are well-equipped to contribute to the digital transformation of construction management practices.

Igwe et al. (2022) conducted an insightful study on the acceptance and application of contemporary technologies in cost management for construction projects, focusing on their potential to enhance efficiency and decision-making processes. The research delved into emerging technologies, including mobile technology, Augmented and Virtual Reality (AR/VR), Building Information Modeling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), and Predictive Analytics (PA), to evaluate their impact on modern cost management practices. The study applied a Technology Acceptance Model (TAM) to assess these technologies across key factors such as availability, affordability, frequency of use, perceived usefulness in cost management, and industry-wide acceptance. Data was collected through a structured questionnaire distributed to Quantity Surveyors in Nigeria, offering a ground-level perspective on the practical application and reception of these technologies. Among the technologies evaluated, mobile technology emerged as the most widely accepted, attributed to its ease of use, affordability, and ability to facilitate real-time data collection. Its flexibility and integration across various construction activities made it a preferred choice for professionals seeking practical and efficient solutions to cost management challenges. While other technologies, such as BIM and AI, were acknowledged for their advanced capabilities, their adoption was limited by factors such as cost, complexity, and the need for specialized training. The study highlighted that mobile technology's accessibility and adaptability bridged the gap between innovation and application, making it the most impactful tool in the current industry context. The authors concluded that fostering wider acceptance of advanced technologies like BIM and AI would require addressing barriers related to affordability, technical expertise, and industry readiness. Nonetheless, the findings underscored the transformative potential of integrating contemporary technologies into cost management practices, emphasizing that mobile technology currently stands as the cornerstone for achieving efficiency and real-time decision-making in construction project

2.8. Research Gap:

Despite the extensive research on digitalization in construction cost management, particularly with the use of Building Information Modeling (BIM), several significant gaps remain unexplored. One notable gap is the limited focus on BIM's long-term cost efficiency. While numerous studies highlight the immediate cost savings that BIM can provide during the design and construction phases, there is a lack of comprehensive research assessing the financial benefits of BIM throughout the entire lifecycle of a building. Current literature predominantly concentrates on short-term benefits, such as minimizing errors and rework, yet additional research is necessary to explore how BIM influences maintenance and operational expenditures over time, particularly in contexts where conventional methods like 2D AutoCAD fail to provide any significant benefits.

Another area with limited exploration is the adoption of BIM in small and medium-sized enterprises (SMEs). Most of the research tends to focus on the implementation of BIM in large-scale construction projects, where the resources to implement and maintain BIM systems are readily available. Conversely, smaller construction companies frequently encounter considerable obstacles to BIM adoption, including high initial costs, insufficient technical skills, and a lack of training opportunities. This situation highlights a research void regarding how these enterprises can navigate such challenges and whether customized versions of BIM can be created to align with the resource limitations faced by SMEs. Furthermore, there is a scarcity of investigation into the tactics that smaller firms can utilize to seamlessly incorporate BIM into their operational processes without incurring prohibitive expenses, a vital consideration that could influence the broader acceptance of digital technologies within the sector. Moreover, while BIM's comparison to traditional tools like 2D AutoCAD is well-documented, there is a gap in research comparing BIM with other emerging technologies such as 3D printing, augmented reality (AR), and digital twins. Present research predominantly centers on drawing comparisons between Building Information Modeling (BIM) and conventional methodologies; however, due to the swift evolution of contemporary technologies, it is critical to investigate how BIM measures up against these advancements concerning cost, efficiency, and sustainability. More research is required to assess how these emerging technologies either complement or compete with BIM and what their integration into construction project management might look like. Additionally, while BIM's benefits in project management and cost estimation have been explored extensively, there is an emerging interest in how BIM can be integrated with IoT (Internet of Things) and AI (Artificial Intelligence) to further enhance predictive cost management. Studies such as those by Kankhva et al. (2021) explore how IoT and AI technologies are transforming real-time data collection, but more research is needed to understand how BIM can work in conjunction with these tools to predict future project costs, resource needs, and maintenance expenses. These integrations have the potential to provide proactive insights into cost and resource optimization, yet there is minimal research detailing the practical applications of these integrations in construction projects. Stakeholder collaboration in construction is another area where there is room for further research. Although studies emphasize BIM's ability to improve communication and collaboration among different project stakeholders, there is limited research on how digitalization fundamentally alters decision-making dynamics in construction. It is important to explore how digital tools, particularly BIM, influence the relationships between different stakeholders, including architects, engineers, contractors, and clients. Research could investigate how digitalization reshapes leadership roles, enhances conflict resolution, and impacts the speed of decision-making in real-time. This presents a gap that could offer insights into the organizational changes required for effective digitalization in construction. Another important gap lies in the area of sustainability. While Byun and Sohn (2020) discuss BIM's potential to enhance sustainability by optimizing energy use and resource allocation, there is a lack of quantitative studies that empirically measure the long-term environmental benefits of BIM. More research is needed to investigate how BIM can reduce a construction project's carbon footprint and contribute to environmentally sustainable practices, especially in comparison to traditional methods. This gap is particularly important as the global construction industry increasingly focuses on sustainable development and minimizing environmental impact. Additionally, there is a lack of standardized frameworks for calculating the return on investment (ROI) from BIM adoption. Current research often highlights cost savings and efficiency improvements but lacks a consistent methodology to quantify the long-term financial benefits of implementing BIM. Developing an industry-wide framework for assessing ROI, particularly for smaller projects and firms, remains an under-researched area. This gap is crucial because construction firms, especially those with limited resources, need clear, quantifiable data to justify the initial investment in BIM technology. And most of the existing literature focuses on BIM adoption in developed economies such as North America, Europe, and Australia, leaving a gap in understanding the challenges and opportunities for BIM adoption in developing countries. These regions often face unique economic, technical, and infrastructural challenges, which may significantly affect the feasibility of implementing BIM. There is a need for more region-specific studies that examine how BIM can be tailored to meet the specific needs of developing countries and what kind of policies or financial incentives could encourage its adoption in such contexts. Human factors involved in BIM implementation have not been studied in detail. While technical and financial aspects of BIM adoption are frequently discussed, there is limited exploration of the psychological, educational, and cultural barriers that professionals face when transitioning from traditional methods to digital ones. More research is needed to understand the resistance to change, the digital skills gap, and how education and training can be improved to encourage broader adoption of BIM across the construction industry. In summary, while BIM and other digital tools have been extensively studied, there are several gaps in the existing research that offer opportunities for future exploration. These include long-term cost efficiency, BIM adoption in smaller firms, comparisons with other emerging technologies, integration with IoT and AI, the human factors involved in digital transformation, and BIM's role in sustainability and ROI measurement. Addressing these gaps could significantly contribute to enhancing our understanding of digitalization in construction cost management and its potential to revolutionize the construction industry.

CHAPTER III:

METHODOLOGY

3.1 Overview of the Research Problem

In the dynamic and ever-changing construction sector, the use of digital technology has become crucial for improving efficiency and effectiveness in different aspects of project management. An essential topic that requires comprehensive examination is the digitization of construction cost management. Although digital tools are increasingly being used in the construction industry, there is still a noticeable lack of understanding regarding the full impact of digitalization on the management of building costs. This study aims to fill this void by examining the difficulties and advantages related to the incorporation of digital technologies in the management of building costs.

The problems faced in the existing cost management professionals includes fragmented process, lack of adequate information, tedious work and time pressure. As per (Lu, Lai and Tse, 2019), the current quality control practices contribute to the division and lack of continuity in the construction industry, which can be reduced by implementing technical and organizational advancements. Quantity surveyors/Cost Managers sometimes do challenge tasks that are typically undervalued by other professions involved in architecture, engineering, and construction.

The research gap in digitalization within construction cost management is the lack of comprehensive investigation into integrated and scalable digital solutions that effectively address the complexities of project cost management. This research to focus on real-time data analytics, interoperability, and the overall influence on project performance and financial outcomes.

3.2 Research Purpose and Questions

The primary purpose of this research is to explore the transformative potential of digitalization in construction cost management, with a focus on enhancing efficiency, accuracy, and stakeholder collaboration. By evaluating the role of digital tools such as Building Information Modeling (BIM) and other emerging technologies, this study aims to address long-standing challenges in the construction industry, including cost overruns, inefficiencies, and miscommunication among stakeholders. The research seeks to provide actionable insights into how these tools can be effectively implemented to streamline processes like quantity take-offs, cost estimation, and real-time project updates. It also aims to identify barriers to digital adoption, such as resistance to change, lack of skills, and high implementation costs, and propose strategies to overcome these obstacles. Ultimately, this study intends to contribute to the knowledge base for industry professionals, policymakers, and technology providers by demonstrating the benefits of digitalization in achieving cost-efficient, sustainable, and collaborative construction practices.

- How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence user perceptions of accuracy and time-saving in construction cost management processes?
- What is the relationship between the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) and its perceived effectiveness in tracking cost variations in construction projects?
- How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence user satisfaction levels in construction cost management?
- What is the relationship between the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) and the perceived effectiveness of providing real-time project cost updates in construction cost management?
- How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence the frequency of miscommunication among stakeholders in construction cost management?
- How does the proficiency level of comprehensive BIM tools compare to hybrid tool approaches in terms of enhancing user performance and satisfaction in construction cost management?
- How does the use of 3D modeling compare to 2D methods in terms of efficiency and time savings for quantity takeoff processes in construction cost management?

- What is the impact of accuracy in time-saving, cost variation tracking, real-time project cost updates, and stakeholder miscommunication on user satisfaction with cost management tools in the construction industry?

These questions aim to provide a comprehensive understanding of the opportunities and challenges associated with digitalization in construction cost management and pave the way for practical recommendations to drive industry-wide adoption.

3.2.1 Hypotheses

Tool Effectiveness in Accuracy and Time Saving

Null Hypothesis (H_0): There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and perceived accuracy and time-saving effectiveness.

Alternative Hypothesis (H_1): There is a significant association between the type of tool used and perceived accuracy and time-saving effectiveness.

Effectiveness in Tracking Cost Variation

Null Hypothesis (H_0): There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and the effectiveness of tracking cost variations.

Alternative Hypothesis (H_1): There is a significant association between the type of tool used and the effectiveness of tracking cost variations.

User Satisfaction with Tools

Null Hypothesis (H_0): There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and user satisfaction.

Alternative Hypothesis (H_1): There is a significant association between the type of tool used and user satisfaction.

Effectiveness in Providing Real-Time Project Cost Updates

Null Hypothesis (H_0): There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and the effectiveness of providing real-time project cost updates.

Alternative Hypothesis (H_1): There is a significant association between the type of tool used and the effectiveness of providing real-time project cost updates.

Frequency of Miscommunication Among Stakeholders

Null Hypothesis (H_0): There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and the frequency of miscommunication among stakeholders.

Alternative Hypothesis (H_1): There is a significant association between the type of tool used and the frequency of miscommunication among stakeholders.

Proficiency Comparison between BIM and Hybrid Tools

Null Hypothesis (H_0): The mean proficiency score for Comprehensive BIM Proficiency is less than or equal to the mean proficiency score for Hybrid Tool Proficiency.

Alternative Hypothesis (H_1): The mean proficiency score for Comprehensive BIM Proficiency is greater than the mean proficiency score for Hybrid Tool Proficiency.

Efficiency of Quantity Take-Off Between 2D and 3D Models

Null Hypothesis (H_0): The mean quantity take-off time using 3D models is greater than or equal to the mean quantity take-off time using 2D methods.

Alternative Hypothesis (H_1): The mean quantity take-off time using 3D models is less than the mean quantity take-off time using 2D methods.

These hypotheses address key aspects of tool effectiveness, user satisfaction, and efficiency, aligning with your study’s objectives to evaluate the impact of digitalization in construction cost management. Let me know if you need further refinements

3.3 Research Design

The research adopts a descriptive and exploratory design, combining quantitative analysis with insights from practical implementation. The descriptive aspect focuses on understanding the current state of digitalization in construction cost management, including usage patterns of digital tools, user satisfaction, and challenges encountered during digital adoption. The exploratory component investigates future trends, such as the potential integration of digital tools with emerging technologies and the long-term feasibility of replacing manual processes with advanced solutions like BIM.

A mixed-method approach is employed to ensure comprehensive coverage of the research objectives. Quantitative data is collected through a structured questionnaire, capturing responses related to the effectiveness of digital tools, user satisfaction, and challenges. Qualitative insights are derived from implementing BIM standards (AEC UK and BS 1192) in real-world scenarios. This combination allows for a robust analysis of trends, relationships, and causal effects

3.4 Population and Sample

The sample population for the present research comprises professionals engaged in the construction sector who are directly participating in cost management activities. This population encompasses architects, engineers, project managers, BIM specialists, and cost managers. Participants represent various sectors, including residential, commercial, infrastructure, and industrial construction, providing a broad understanding of industry practices. Geographically, the study focuses on the Indian construction industry while offering insights that are globally relevant.

A purposive sampling technique is used to ensure that participants have relevant experience with construction cost management and digital tools. The sample size consists of 238 respondents, selected to provide a diverse and comprehensive dataset. Respondents include professionals with varying levels of experience: those with 0-5 years of experience represent younger professionals and early adopters, while those with 6-10 years and 11-20 years provide perspectives from mid-level and senior professionals. This diversity ensures a balanced representation of industry practices and challenges across roles, including architects, project managers, cost managers, and technology specialists.

3.5 Data Collection Procedures

The research methodology is structured to integrate three main components: a quantitative approach, process implementation, and a comprehensive literature review. Each component contributes uniquely to achieving the research objectives and ensures that the study is both robust and aligned with industry best practices.

The quantitative approach serves as the primary focus of the research. This involves the collection of structured data through a well-designed questionnaire distributed to professionals in the construction industry. The questionnaire is tailored to gather insights on various aspects of digitalization in construction cost management, including tool usage, effectiveness, challenges, and future trends. The data collected is analyzed using statistical methods such as descriptive statistics, Chi-square tests, t-tests, and regression analysis. These analyses enable the identification of trends, relationships, and causal effects, offering a data-driven understanding of how digital tools impact cost management processes and user satisfaction. The quantitative approach ensures the research remains objective and provides reliable evidence to address the research questions.

The process implementation aspect emphasizes the practical application of digital tools and adherence to established industry standards, specifically the AEC (UK) BIM Standard for Revit and BS 1192 standards. This component involves converting 2D CAD drawings into LOD 350 models, performing quantity take-offs, generating bills of materials, conducting visualization and clash detection, and ensuring seamless coordination among stakeholders. The adherence to these standards ensures that the findings are grounded in real-world practices and demonstrate the practical benefits and challenges of digitalization in construction projects. By implementing these standards, the research validates theoretical insights and provides a deeper understanding of how digital tools can be effectively integrated into construction cost management workflows.

The literature review provides the secondary data needed to establish a theoretical foundation for the research. It involves a systematic review of existing studies, journals, and reports to explore the current state of digitalization in construction, identify knowledge gaps, and understand the challenges and opportunities faced by the industry. The literature review contextualizes the primary data findings and ensures that the research aligns with previous work while contributing new insights. This component also helps in benchmarking practices and identifying best-case scenarios for implementing digital tools in cost management.

By integrating these three components, the research approach ensures a comprehensive and balanced investigation of the role of digitalization in construction cost management, combining theoretical insights, practical application, and empirical evidence to achieve the study's objectives.

Process Implementation

The process implementation forms a significant component of this study, focusing on the practical application of digital tools and adherence to industry standards to validate the research findings. This phase integrates established protocols and technologies to ensure that the research aligns with best practices in construction cost management.

The implementation is anchored in two key standards: the AEC (UK) BIM Standard for Revit and BS 1192 standards. The AEC (UK) BIM Standard provides a comprehensive framework for using Autodesk Revit within the architecture, engineering, and construction (AEC) disciplines. It offers detailed guidelines on structuring, managing, and sharing BIM models to maintain consistency and clarity across all project phases. The BS 1192 standard complements this by providing a collaborative framework for managing and sharing information across the entire project lifecycle. Together, these standards ensure that the processes implemented in the study are structured, efficient, and aligned with international best practices.

The key activities involved in this phase include:

Conversion of 2D CAD Drawings to LOD 350 Models:

This activity begins with the collection of all relevant 2D design documentation, including architectural, structural, mechanical, electrical, and plumbing (MEP) drawings. These documents are used as the basis for creating 3D models in Autodesk Revit. The 3D modeling process incorporates detailed data integration, including material properties, dimensions, and construction methods, to achieve a Level of Development (LOD) 350. This level of detail ensures the models are precise and sufficient for construction documentation and coordination among disciplines.

Quantity Take-offs and Bill of Materials Generation:

Using the LOD 350 models, accurate quantity take-offs are performed. These take-offs form the foundation for generating Bills of Materials (BOM), providing a detailed list of all components and resources required for the project. This step ensures precise cost estimation and resource planning, reducing the likelihood of discrepancies during the construction phase.

Visualization and Clash Detection:

Visualization tools within Autodesk Revit and other BIM platforms are used to create realistic representations of the construction project. These visualizations facilitate better communication and understanding among stakeholders. Additionally, clash detection is conducted to identify and resolve potential conflicts between various systems, such as structural elements and MEP installations. This step ensures a smoother construction process by addressing issues during the design phase rather than on-site.

Stakeholder Coordination:

Collaboration is a critical aspect of BIM implementation. The centralized BIM model serves as a single source of truth for all stakeholders, enabling seamless coordination among architects, engineers, contractors, and project managers. Regular reviews and updates ensure that all parties are aligned with project goals and changes, fostering transparency and efficiency throughout the project lifecycle.

By implementing these activities, the study demonstrates the practical application of digital tools and industry standards in construction cost management. This process not only validates the theoretical findings but also highlights the benefits and challenges of digitalization in real-world scenarios. The adherence to established standards ensures that the findings are relevant, reliable, and aligned with global practices in construction cost management.

Process Summary

For the commencement of this project, we implemented the AEC (UK) BIM Standard for Revit and adhered to the BS 1192 standards to ensure that all processes, data management, and collaboration frameworks were aligned with industry best practices. The application of these standards was pivotal in facilitating a structured and consistent approach to BIM implementation across the project lifecycle, ensuring accuracy, clarity, and efficiency in both design and construction phases.

The AEC (UK) BIM Standard for Revit is a robust framework designed specifically to standardize the use of Autodesk Revit across architectural, engineering, and construction disciplines. It provides a comprehensive set of guidelines and protocols that dictate how BIM should be structured, managed, and shared, ensuring that all stakeholders operate using consistent methodologies within a Revit environment

Process:

1. Converting 2D CAD (Computer-Aided Design) drawings to LOD 350 (Level of Development 350) model.
2. Quantity take-offs
3. Creation of Bill of Materials.
4. Visualisation and clash detection
5. Coordination between Stakeholders

Converting 2D CAD (Computer-Aided Design) drawings to LOD 350 (Level of Development 350) model.

Data Collection: The initial phase involves collecting all relevant 2D design documentation, including architectural, structural, and MEP drawings, which will serve as the basis for the 3D model.

CHECKLIST for developing 2D drawings to LOD 350 :

1. Gather 2D CAD Drawings.
2. Architectural details.
3. Mechanical Systems details.
4. Electrical Systems details.
5. Interior Elements details.
6. Site Elements.

Modelling Process: **A team of skilled BIM technicians** and drafters converts the 2D drawings into 3D models. Key architectural components, structural elements, and building systems are modelled with a focus on accuracy and detail. For LOD 350 model timeline with resources

Data Integration: During the LOD 300 modelling, data such as material properties, dimensions, and other relevant information are integrated into the model, enhancing its value for design coordination and early project analysis.

Creating a 3D model in Revit using AutoCAD drawings involves importing the AutoCAD file into Revit and then using the tools in Revit to build the 3D model. Here are the general steps:

Prepare AutoCAD Drawing:

Ensure that your AutoCAD drawing is organised and clean. Check for any errors or missing elements.

Save the AutoCAD drawing in a format compatible with Revit, such as DWG.

Open Revit:

Launch Autodesk Revit on your computer.

Start a New Project or Open Existing Project:

Create a new project or open an existing project where you want to import the AutoCAD drawing.

Set Up Units and Levels:

Verify that the units in Revit match the units used in AutoCAD. Adjust them if necessary.

Set up the levels and grids in Revit to match the structure of your AutoCAD drawing.

Import AutoCAD Drawing:

- Go to the "Insert" tab in Revit.
- Choose "Import CAD" from the Import panel.
- Locate and select your AutoCAD file.
- Follow the prompts to configure import settings. Ensure that the correct layers and levels are selected for import.

Place DWG Elements:

- Once the AutoCAD drawing is imported, you may need to place individual DWG elements into the appropriate views.

Create Walls, Floors, and Roofs:

- Use the drawing and modelling tools in Revit to create walls, floors, and roofs based on the imported AutoCAD elements.

Build Additional Components:

- Add doors, windows, and other components using Revit's modelling tools. Ensure they align with the imported drawing.

Modify and Fine-Tune:

- Adjust the model as needed, making modifications to elements, adjusting heights, and refining the details.

Coordinate with 3D Views:

- Use 3D views in Revit to visualise and coordinate the 3D model. Ensure that the elements are correctly positioned and aligned.

Apply Materials and Textures:

- Assign materials and textures to the model to enhance its visual representation. This step helps in creating a more realistic and visually appealing 3D model.

Review and Revise:

- Review the 3D model in different views and make any necessary revisions to ensure accuracy and completeness.

Documentation:

- Create construction documentation, including plans, elevations, and sections, based on the 3D model.

Quantity take off

Quantity Takeoff (QTO) is an essential process in construction, used to calculate the quantities of materials, labor, and resources needed for a project. The integration of Quantity Takeoff within Building Information Modeling (BIM) has revolutionized this process by enhancing accuracy, efficiency, and collaboration. This section outlines the detailed steps involved in performing a quantity takeoff in a BIM model and examines how this approach improves project planning and execution.

Steps for Performing Quantity Takeoff in a BIM Model:

Model Preparation and Data Validation: Before conducting a quantity takeoff, it is essential to ensure that the BIM model is complete and contains accurate and detailed information. This includes verifying that all elements within the model, such as walls, floors, columns, mechanical systems, and finishes, have been correctly defined with appropriate dimensions, material properties, and quantities. The model should be classified based on recognized standards like the Uniformat or MasterFormat to ensure consistent reporting.

Assign Relevant Parameters to Model Elements: For accurate quantity takeoff, model elements must have assigned parameters that include necessary data such as material type, volume, surface area, length, and other relevant metrics. These parameters should be correctly linked to construction specifications, as they form the foundation for extracting material quantities from the model.

Select Appropriate BIM Tools for Quantity Takeoff: Various BIM software platforms, such as Autodesk Revit, Navisworks, and Tekla, offer integrated tools for performing quantity takeoff. These tools allow users to extract detailed material quantities directly from the 3D model. Select a tool that aligns with the project’s specific needs, ensuring that it supports accurate measurement and reporting based on the model's data.

Generate and Customize Schedules: The next step involves generating quantity schedules within the BIM model. Most BIM platforms allow the creation of customizable schedules that automatically extract quantities for specific elements (e.g., concrete volumes, steel tonnage, or square footage of finishes). Users can customize these schedules to include the necessary parameters, group quantities by element type or material, and filter information based on specific criteria (e.g., floors, zones, or phases of construction).

Refine Quantity Takeoff for Specific Elements: In more complex projects, different elements may require specialized takeoff methods. For example, structural components (like steel or concrete) need to be measured for volume or weight, while architectural finishes may need surface area calculations. Refine the quantity takeoff process by grouping and categorizing elements based on their specific takeoff requirements. This ensures that quantities are accurately aligned with the construction requirements.

Cross-Check and Verify Quantities: Once the schedules have been generated, the next step is to cross-check and verify the extracted quantities against the model and design documentation. This verification process ensures that no elements have been omitted, and the quantities match the design intent. It also helps in identifying any discrepancies or errors within the model that may affect the accuracy of the takeoff.

Adjust for Project Phases and Construction Sequences: Quantity takeoff in a BIM model can be further refined to account for different phases of the project or construction sequences. By filtering elements based on the construction schedule, users can extract material quantities needed for specific project milestones (e.g., foundation, superstructure, finishes). This step allows for better planning and procurement strategies, aligning the takeoff with the project timeline.

Export Quantities for Cost Estimation and Analysis: After completing the quantity takeoff process, the extracted quantities can be exported for further analysis. Most BIM tools allow users to export schedules in formats such as Excel or CSV, which can then be used for cost estimation, budgeting, and procurement planning. The quantities extracted from the BIM model form the basis for creating detailed cost estimates and ensuring that the project remains within budget.

Steps for quantity take off

Open the Revit Project:

- Launch Revit and open the project containing the 3D model from which you want to extract quantities.

Create or Open a Schedule:

- Go to the View tab on the ribbon.
- Select "Schedules" and then choose "Schedule/Quantities."

Select the Category for Quantity Extraction:

- In the New Schedule dialog box, choose the category of elements you want to extract quantities for (e.g., walls, doors, windows, etc.).

Define Fields in the Schedule:

- In the Fields tab, add the parameters you want to include in the schedule. For quantities, you might want to include parameters like Length, Area, Volume, etc., depending on the type of element.

Group and Sort Data (Optional):

- Use the Grouping and Sorting tabs in the Schedule Properties to organise the data in a way that makes sense for your project.

Filter Data (Optional):

- Apply filters if you only want to include specific elements in the schedule. Filters can be based on parameters such as Type, Level, or any other parameter relevant to your project.

Adjust Formatting:

- Customise the appearance and formatting of the schedule in the Formatting tab. This includes specifying units, rounding, and other display options.

Load the Schedule into a Sheet (Optional):

- You may want to place the schedule on a sheet for documentation purposes. To do this, go to the View tab, select "Sheet Composition," and drag the schedule onto the sheet.

Export the Schedule to Excel (Optional):

- If you need to perform further analysis or share the quantities with others, you can export the schedule to Excel. Right-click on the schedule in the project browser and select "Export" > "Reports" > "Schedule."

Review and Verify Quantities:

- Double-check the quantities in the schedule to ensure they align with your expectations. Verify that the parameters and filters are correctly set up.
  Repeat for Other Categories (If Necessary):

- If you need quantities for multiple categories, repeat the process by creating additional schedules for each category.
  Save and Share:
- Save your Revit project to retain the schedules and any changes you made. Share the extracted quantities with relevant team members as needed.

Creation of Bill of Materials.

In Building Information Modeling (BIM), the integration of specifications is critical for ensuring that detailed design requirements, material standards, and construction methods are clearly defined within the model. Specifications form the basis of construction documentation and play a pivotal role in guiding the project execution phase. This section outlines the structured steps for adding specifications to a BIM model and explores the key advantages this integration offers.

Steps for Adding Specifications to a BIM Model:

Develop a Clear Specification Framework: Before integrating specifications into the BIM model, it is essential to establish a comprehensive framework. This involves creating a well-organized specification document that includes all necessary details such as material types, performance criteria, construction methods, and quality standards. These documents typically follow industry-specific guidelines like the Construction Specifications Institute (CSI) MasterFormat.

Link Specifications to Model Elements: Once the specification framework is in place, the next step is to link each specification to its corresponding element in the BIM model. This can be done by assigning attributes or parameters to specific components such as walls, floors, mechanical systems, and finishes. For instance, a wall element in the model can be linked to its specification detailing the required material (e.g., concrete type, fire rating, and thermal insulation properties).

Utilize BIM Software Tools for Integration: Modern BIM platforms such as Autodesk Revit, ArchiCAD, and others provide tools that allow users to embed specifications directly into the model. These tools enable the seamless integration of specification data as parameters attached to individual elements. By leveraging these tools, users can ensure that all specifications are centrally stored within the model and are easily accessible to project stakeholders.

Ensure Consistency Between Model and Documentation: As specifications evolve during the design and construction process, it is critical to maintain consistency between the BIM model and the associated construction documentation. This step involves regularly updating both the model and the specification documents to reflect any design changes, ensuring alignment across all project stages.

3.6 Data Analysis

The data analysis phase is a crucial step in examining the collected data to derive meaningful insights and validate the research objectives. This phase employs a combination of descriptive and inferential statistical methods to explore the impact of digitalization on construction cost management. The structured approach ensures a comprehensive evaluation of trends, relationships, and variations among the studied variables, addressing key research questions effectively.

3.6.1. Descriptive Statistics

The analysis begins with descriptive statistics, providing an overview of the demographic composition, tool usage, and satisfaction levels of the respondents. Demographic data such as gender, years of experience, and professional roles offer insights into the diverse representation within the sample. Tool usage patterns reveal that AutoCAD with MS Office and BIM with MS Office are the most frequently used, highlighting varying levels of adoption of digital tools. Additionally, satisfaction levels with current tools are assessed to establish baseline user perceptions. These findings are summarized using frequency distributions, percentages, and visual aids like bar charts, offering a clear snapshot of the data.

3.6.2. Inferential Statistics

Inferential statistical methods are employed to uncover significant relationships between variables. Chi-square tests analyze the association between tool type and user perceptions of accuracy, time savings, and satisfaction. For example, these tests validate that BIM tools are statistically more associated with higher accuracy and efficiency compared to traditional tools like AutoCAD. Paired sample t-tests are used to compare performance metrics, such as time efficiency, between traditional and digital tools. The results demonstrate significant time savings with 3D modeling over 2D methods, providing empirical evidence of the advantages of modern digital tools.

3.6.3. Advanced Analyses and Insights

Regression analysis is used to examine the predictive relationships between multiple variables, such as accuracy, real-time updates, and cost tracking, and their influence on user satisfaction. Real-time updates emerge as the most significant predictor, highlighting their critical role in enhancing user experience. Comparative analysis further evaluates the strengths and limitations of traditional tools (e.g., AutoCAD) versus modern tools (e.g., BIM), focusing on accuracy, time savings, and stakeholder coordination. These advanced analyses offer actionable insights and validate the findings with empirical evidence, underscoring the transformative potential of digitalization in construction cost management.

3.7 Research Design Limitations

The research methodology employed in this study has certain limitations that should be acknowledged. The use of purposive sampling, while ensuring insights from experienced professionals in construction cost management, may introduce sampling bias and limit the generalizability of findings to broader industry contexts or regions with differing digital adoption levels. Additionally, the focus on the Indian construction industry constrains the applicability of results to global practices, as unique economic, regulatory, and cultural factors may not translate across borders. The reliance on self-reported data through structured questionnaires presents the potential for response bias, where participants might overestimate their digital tool usage or provide socially desirable responses. Furthermore, the study's qualitative insights, drawn from specific BIM implementation processes, lack broader representation, which could limit the depth of understanding regarding real-world challenges. The emphasis on specific BIM standards such as AEC (UK) and BS 1192 might narrow the scope, excluding other tools or methods relevant in diverse construction environments. Time constraints during data collection restricted the ability to capture long-term trends in digital adoption, while the statistical methods used, such as Chi-square tests and regression analysis, may not fully explore complex interactions or predict long-term impacts. Moreover, the rapid evolution of technology, including AI and blockchain, which were not extensively analyzed, poses a challenge to the long-term relevance of the findings. Addressing these limitations in future research could provide a more comprehensive and globally relevant perspective on digitalization in construction cost management.

3.8. Ethical Considerations

Ethical considerations are a vital aspect of any research process, ensuring the rights, privacy, and well-being of participants are protected throughout the study. This research adhered to established ethical guidelines to maintain the highest standards of integrity and responsibility in data collection, analysis, and reporting.

Participation in this study was entirely voluntary. Respondents were provided with a clear explanation of the research purpose, objectives, and the scope of the study before participation. This information was included at the beginning of the questionnaire, allowing participants to make an informed decision about their involvement. A consent statement was provided, and only those who explicitly agreed to participate were included in the study. This approach ensured that all participants willingly contributed to the research without any form of coercion or undue influence. To safeguard the privacy and confidentiality of the respondents, strict measures were implemented to anonymize the data. No personal identifying information was collected as part of the questionnaire, ensuring that responses could not be traced back to individual participants. The data was securely stored and accessed only by authorized personnel involved in the research. Anonymization ensured that participants' identities remained protected, fostering a sense of trust and security.

The data collected was used exclusively for academic purposes and in alignment with the research objectives. The findings were presented in aggregate form, ensuring that individual responses were not identifiable. This practice not only upholds confidentiality but also reinforces the credibility of the research by adhering to ethical data handling protocols.

3.9 Conclusion

The research methodology outlined in this chapter establishes a robust framework for investigating the role of digitalization in construction cost management. By adopting a mixed-method approach that integrates quantitative data collection, process implementation, and a comprehensive literature review, the study ensures a holistic and rigorous analysis of the research objectives.

The descriptive and exploratory research design facilitates a nuanced understanding of current practices, challenges, and opportunities associated with digital tools like BIM in the construction industry. The use of purposive sampling ensures that the study captures relevant perspectives from professionals actively involved in cost management processes, contributing to the reliability and applicability of the findings. The detailed process implementation adheres to established industry standards, bridging theoretical insights with practical applications to validate the study's outcomes.

A systematic approach to data analysis, encompassing descriptive statistics, inferential tests, and regression analysis, ensures a comprehensive evaluation of the collected data. The formulation and testing of hypotheses align with the research objectives, offering actionable insights into the effectiveness, satisfaction, and efficiency associated with digital tools in construction cost management.

This methodology not only addresses the key questions of the study but also sets the foundation for credible and impactful conclusions, contributing valuable insights into the transformative potential of digitalization in the construction industry.

CHAPTER IV:

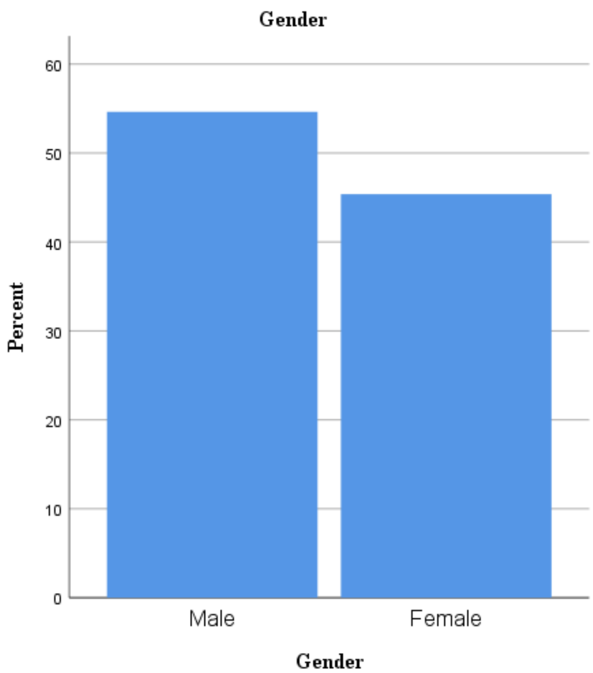
RESULTS

4.1. Descriptive Statistics:

Table 1 : Gender:

S.No	Category	Frequency	Percent
1	Male	130	54.6
2	Female	108	45.4
	Total	238	100

Fig 1 : Bar Chart (Gender)



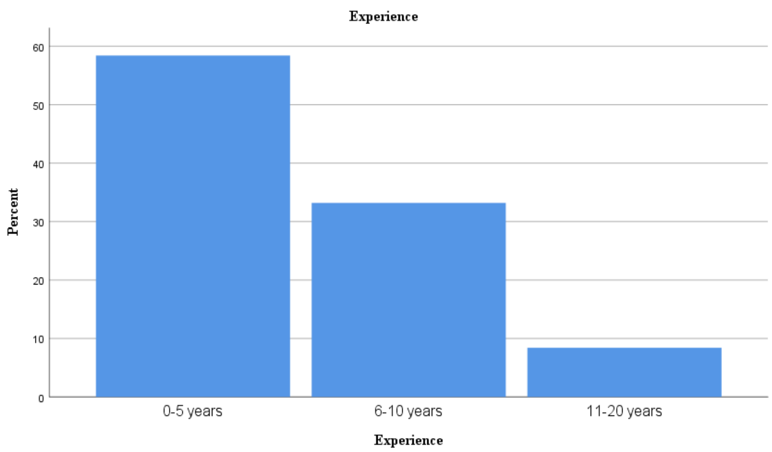
Interpretation:

The data shows the gender distribution among 238 respondents, with 130 males comprising 54.6% and 108 females accounting for 45.4%. This indicates a slight majority of male respondents, though the sample remains relatively balanced. Such a distribution provides a fairly even representation of both genders

Table 2 : Experience:

S.No	Category	Frequency	Percent
1	0-5 years	139	58.4
2	6-10 years	79	33.2
3	11-20 years	20	8.4
	Total	238	100

Fig 2 :Bar Chart (Experience)

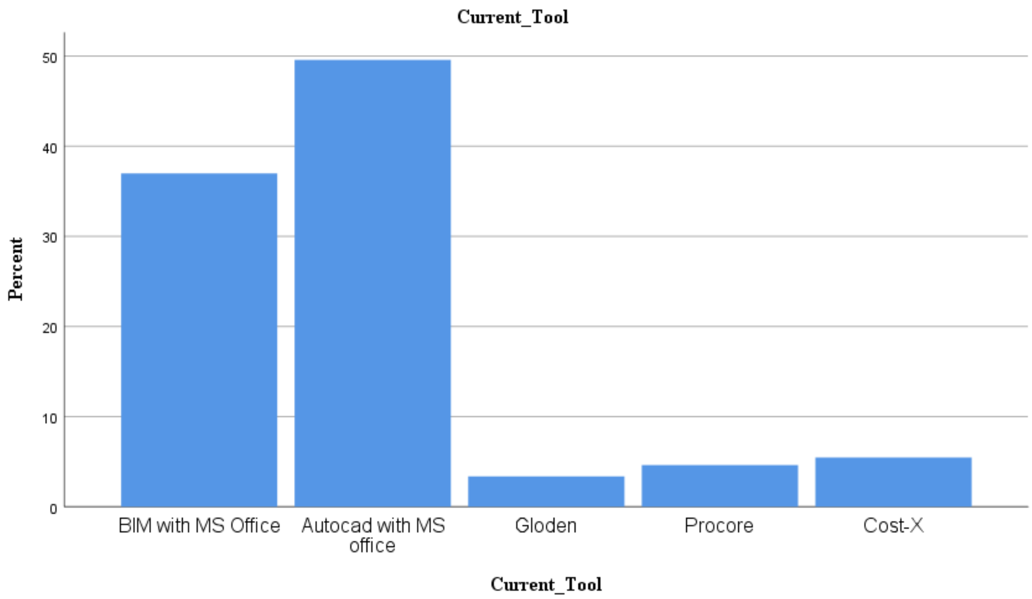


The data represents the distribution of respondents based on their years of experience. The majority, 139 respondents (58.4%), have 0-5 years of experience, indicating a predominantly less experienced group. This is followed by 79 respondents (33.2%) with 6-10 years of experience. Only 20 respondents (8.4%) have 11-20 years of experience, making them the smallest group.

Table 3 : Current Tool:

S.No	Category	Frequency	Percent
1	BIM with MS Office	88	37
2	Autocad with MS office	118	49.6
3	Gloden	8	3.4
4	Procore	11	4.6
5	Cost-X	13	5.5
	Total	238	100

Fig 3 : Current Tool



The data shows the distribution of respondents based on their current tool usage. The most commonly used tool is AutoCAD with MS Office, with 118 respondents (49.6%), followed by BIM with MS Office, used by 88 respondents (37%). Other tools include Cost-X with 13 respondents (5.5%), Procore with 11 respondents (4.6%), and Gloden with 8 respondents (3.4%).

4.2. Research Question One :

How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence user perceptions of accuracy and time-saving in construction cost management processes?

Table 4 : Chi Square Test: (Accuracy and Time Saving)

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18.833a	3	0.000
Likelihood Ratio	20.036	3	0.000
Linear-by-Linear Association	17.647	1	0.000
N of Valid Cases	206		

Table 5 : Post-Hoc Chi Square Test:

Crosstab						
Current_Tool	**Accuracy_Time_Saving**					**Total**
		Somewhat Accurate	Moderately Accurate	Accurate	Highly Accurate	
BIM with MS Office	Count	3	10	41	34	88
	Expected Count	8.5	17.9	36.3	25.2	88
	Standardized Residual	-1.9	-1.9	0.8	1.8	
Autocad with MS office	Count	17	32	44	25	118
	Expected Count	11.5	24.1	48.7	33.8	118
	Standardized Residual	1.6	1.6	-0.7	-1.5	
	Count	20	42	85	59	206
	Expected Count	20	42	85	59	206

Hypotheses

Null Hypothesis (H_0):

There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and Accuracy cum time-saving.

Alternative Hypothesis (H_1):

There is a significant association between the type of tool used and Accuracy cum time saving

Interpretation of Results

The Chi-Square test shows a **significant association** between the type of tool and perceived time-saving accuracy χ^2 **=18.833, p<0.001**. This indicates that user perceptions on accuracy cum time-saving differ depending on the type tool used.

Post-Hoc Analysis (Standardized Residuals)

- **BIM with MS Office** performs better in the **Highly Accurate** category, with a standardized residual of **+1.8**, indicating more users find it highly accurate than expected.

- Conversely, **AutoCAD with MS Office** has higher counts in the **Somewhat Accurate** and **Moderately Accurate** categories (residuals **+1.6** each) and underperforms in the **Highly Accurate** category (**-1.5**).

BIM with MS Office is more frequently associated with higher time-saving accuracy, making it a potentially better tool for users seeking precision and efficiency. In contrast, **AutoCAD with MS Office** is more commonly linked with moderate accuracy levels.

4.3. Research Question Two :

What is the relationship between the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) and its perceived effectiveness in tracking cost variations in construction projects?

Table 6 : Chi Square Test: (Tracking_Cost_Variation)

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	23.252a	4	0.000
Likelihood Ratio	24.628	4	0.000
Linear-by-Linear Association	17.682	1	0.000
N of Valid Cases	206		

Table 7 : Tracking_Cost_Variation

Crosstab							
Current_Tool		**Tracking_Cost_Variation**					**Total**
		Not Effective	Somewhat Effective	Moderately Effective	Effective	Highly Effective	
BIM with MS Office	Count	0	3	21	37	27	88
	Expected Count	0.4	8.5	23.5	40.2	15.4	88
	Standardized Residual	-0.7	-1.9	-0.5	-0.5	3	
Autocad with MS office	Count	1	17	34	57	9	118
	Expected Count	0.6	11.5	31.5	53.8	20.6	118
	Standardized Residual	0.6	1.6	0.4	0.4	-2.6	
	Count	1	20	55	94	36	206
	Expected Count	1	20	55	94	36	206

Hypotheses

Null Hypothesis (H_0):

There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and perceived effectiveness in tracking cost variations.

Alternative Hypothesis (H_1):

There is a significant association between the type of tool used and perceived effectiveness in tracking cost variations.

Interpretation of Results

The Chi-Square test shows a significant association between the type of tool and perceived effectiveness in tracking cost variations **χ^2 =23.252, p<0.001**. This indicates that user perceptions of tracking cost variations differ depending on the tool used.

Post-Hoc Analysis (Standardized Residuals)

BIM with MS Office performs notably better in the **Highly Effective** category, with a standardized residual of **+3.0**, indicating more users find it highly effective than expected.

Conversely, **AutoCAD with MS Office** underperforms in the **Highly Effective** category, with a standardized residual of **-2.6**, suggesting fewer users rate it highly effective than expected.

AutoCAD with MS Office has higher counts in the **Somewhat Effective** category (residual **+1.6**) and performs close to expected in other categories.

BIM with MS Office is more frequently associated with higher effectiveness in tracking cost variations, making it a more suitable tool for users seeking precise and effective cost management. In contrast, **AutoCAD with MS Office** is more commonly associated with lower effectiveness, particularly in the **Somewhat Effective** category.

4.4. Research Question Three :

How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence user satisfaction levels in construction cost management?

Table 8 : Chi Square Test: (Satisfaction_of_Current_Tool)

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	17.948a	4	0.001
Likelihood Ratio	19.137	4	0.001

Linear-by-Linear Association	17.81	1	0
No of Valid Cases	206		

Table 9 : Satisfaction_of_Current_Tool

Crosstab							
Current_Tool		**Satisfaction_of_Current_Tool**					**Total**
		Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	
BIM with MS Office	Count	0	4	16	37	31	88
	Expected Count	0.4	10.3	22.2	33.3	21.8	88
	Standardized Residual	-0.7	-2	-1.3	0.6	2	
Autocad with MS office	Count	1	20	36	41	20	118
	Expected Count	0.6	13.7	29.8	44.7	29.2	118
	Standardized Residual	0.6	1.7	1.1	-0.6	-1.7	
	Count	1	24	52	78	51	206

	Expected Count	1	24	52	78	51	206

Hypotheses

Null Hypothesis (H_0):

There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and user satisfaction with the current tool.

Alternative Hypothesis (H_1):

There is a significant association between the type of tool used and user satisfaction with the current tool.

Interpretation of Results

The Chi-Square test reveals a significant association between the type of tool used and user satisfaction χ^2 **=17.948, p=0.001**. This indicates that user satisfaction levels differ depending on the tool being used.

Post-Hoc Analysis (Standardized Residuals)

BIM with MS Office performs significantly better in the **Very Satisfied** category, with a standardized residual of **+2.0**, indicating that more users are very satisfied than expected.

AutoCAD with MS Office overperforms in the **Dissatisfied** category, with a standardized residual of **+1.7**, indicating more users are dissatisfied than expected.

BIM with MS Office is more frequently associated with higher user satisfaction, particularly in the **Very Satisfied** category. In contrast, **AutoCAD with MS Office** is more commonly linked with dissatisfaction. This suggests that **BIM with MS Office** provides a better user experience in terms of satisfaction.

4.5. Research Question Four :

What is the relationship between the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) and the perceived effectiveness of providing real-time project cost updates in construction cost management?

Table 10 : Chi Square Test: (Project_Cost_Real_Time_Update)

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18.019a	4	0.001
Likelihood Ratio	22.747	4	0.000
Linear-by-Linear Association	16.338	1	0.000
N of Valid Cases	206		

Table 11 : Project_Cost_Real_Time_Update

Crosstab							
Current_Tool		**Project_Cost_Real_Time_Update**					**Total**
		Not effective	somewhat effective	Moderately Effective	Effective	Highly Effective	
BIM with MS Office	Count	0	3	19	37	29	88
	Expected Count	5.6	3.4	23.1	35.9	20.1	88
	Standardized Residual	-2.4	-0.2	-0.8	0.2	2	
Autocad with MS office	Count	13	5	35	47	18	118
	Expected Count	7.4	4.6	30.9	48.1	26.9	118

	Standardized Residual	2	0.2	0.7	-0.2	-1.7	
	Count	13	8	54	84	47	206
	Expected Count	13	8	54	84	47	206

Hypotheses

Null Hypothesis (H_0):

There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and the perceived effectiveness of real-time project cost updates.

Alternative Hypothesis (H_1):

There is a significant association between the type of tool used and the perceived effectiveness of real-time project cost updates.

Interpretation of Results

The Chi-Square test shows a significant association between the type of tool and perceived effectiveness of real-time project cost updates **χ^2 =18.019, p=0.001**. This indicates that user perceptions of real-time cost update effectiveness vary depending on the tool used.

Post-Hoc Analysis (Standardized Residuals)

BIM with MS Office performs significantly better in the **Highly Effective** category, with a standardized residual of **+2.0**, indicating that more users find it highly effective than expected.

AutoCAD with MS Office overperforms in the **Not Effective** category, with a standardized residual of **+2.0**, suggesting more users found it not effective than expected.

BIM with MS Office is more frequently associated with higher effectiveness in providing real-time project cost updates, particularly in the **Highly Effective** category. In contrast, **AutoCAD with MS Office** tends to be rated as less effective, with more users finding it **Not Effective**. This suggests that **BIM with MS Office** is the better tool for real-time cost management.

4.6. Research Question Five :

How does the type of digital tool used (BIM with MS Office vs. AutoCAD with MS Office) influence the frequency of miscommunication among stakeholders in construction cost management?

Table 12 : Chi Square Test: (Misscommunication_Stakeholders)

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	24.605a	4	0.000
Likelihood Ratio	26.617	4	0.000
Linear-by-Linear Association	24.099	1	0.000
N of Valid Cases	206		

Table 13 : Misscommunication_Stakeholders

Crosstab							
Current_Tool		**Misscommunication_Stakeholders**					**Total**
		Very Often	Often	Sometimes	Rarely	Never	
BIM with MS Office	Count	0	7	21	42	18	88
	Expected Count	1.3	16.2	26.5	32.5	11.5	88
	Standardized Residual	-1.1	-2.3	-1.1	1.7	1.9	
Autocad with MS office	Count	3	31	41	34	9	118

	Expected Count	1.7	21.8	35.5	43.5	15.5	118
	Standardized Residual	1	2	0.9	-1.4	-1.6	
	Count	3	38	62	76	27	206
	Expected Count	3	38	62	76	27	206

Hypotheses

Null Hypothesis (H_0):

There is no significant association between the type of tool used (BIM with MS Office vs. AutoCAD with MS Office) and the frequency of miscommunication among stakeholders.

Alternative Hypothesis (H_1):

There is a significant association between the type of tool used and the frequency of miscommunication among stakeholders.

Interpretation of Results

The Chi-Square test shows a significant association between the type of tool and the frequency of miscommunication among stakeholders **$\chi^2 = 24.605$, $p<0.001$**. This indicates that the frequency of miscommunication differs based on the tool used.

Post-Hoc Analysis (Standardized Residuals)

- **BIM with MS Office** underperforms in the **Often** category, with a standardized residual of **-2.3**, indicating fewer users report frequent miscommunication than expected.

- **AutoCAD with MS Office** overperforms in the **Often** category, with a standardized residual of **+2.0**, indicating more users report frequent miscommunication than expected.

BIM with MS Office is associated with less frequent miscommunication among stakeholders, as indicated by higher counts in the **Rarely** and **Never** categories. In contrast, **AutoCAD with MS Office** is linked to more frequent miscommunication, particularly in the **Often** category. This suggests that **BIM with MS Office** may offer better communication efficiency.

4.7. Research Question Six :

How does the proficiency level of comprehensive BIM tools compare to hybrid tool approaches in terms of enhancing user performance and satisfaction in construction cost management?

Table 14 : Paired Sample t-Test: (Proficiency)

	Comprehensive BIM Proficiency	**Hybrid Tool Proficiency**
Mean	19.66990291	18.45145631
Variance	4.680748283	14.79519299
Observations	206	206
df	205	
t Stat	4.770268769	
P(T<=t) one-tail	1.74467E-06	Reject H_0
t Critical one-tail	1.652320556	
P(T<=t) two-tail	3.48933E-06	Reject H_0
t Critical two-tail	1.971603499	

Hypotheses For One tailed

Null Hypothesis (H_0):

The mean score for Comprehensive BIM Proficiency is less than or equal to the mean score for Hybrid Tool Proficiency.

H_0: μComprehensive BIM Proficiency $\leq$ μ Hybrid Tool Proficiency

Alternative Hypothesis (H_1):

The mean score for Comprehensive BIM Proficiency is greater than the mean score for Hybrid Tool Proficiency

H_1: μComprehensive BIM Proficiency $>$ μ Hybrid Tool Proficiency

Hypotheses For Two tailed

Null Hypothesis (H_0):

There is no significant difference in the mean scores between Comprehensive BIM Proficiency (Variable 1) and Hybrid Tool Proficiency (Variable 2).

H_0: μComprehensive BIM Proficiency = μ Hybrid Tool Proficiency

Alternative Hypothesis (H_1):

There is a significant difference in the mean scores between Comprehensive BIM Proficiency and Hybrid Tool Proficiency.

H_1: μComprehensive BIM Proficiency $\neq$ μ Hybrid Tool Proficiency

Interpretation:

Mean Difference

The mean score for Comprehensive BIM Proficiency is 19.67, while the mean score for Hybrid Tool Proficiency is 18.45. This indicates that, on average, users rate Comprehensive BIM Proficiency higher than Hybrid Tool Proficiency. The observed difference in mean scores suggests that tools categorized under Comprehensive BIM Proficiency are perceived to offer better overall proficiency compared to those under Hybrid Tool Proficiency.

t-Statistic

The calculated t-statistic is **4.77**, which exceeds the critical values for both one-tailed and two-tailed tests. This value reflects the magnitude of the difference between the two sets of scores, adjusted for sample size and variance. A higher t-statistic indicates that the observed difference in means is unlikely to have occurred by chance, reinforcing the significance of the results.

p-Values

The one-tailed p-value is $\mathbf{1.74 \times 10^{-6}}$, and the two-tailed p-value is $\mathbf{3.49 \times 10^{-6}}$, both of which are significantly less than the standard significance level of **0.05**. These p-values provide strong evidence to reject the null hypothesis, confirming that the difference in means between the two proficiencies is statistically significant. The very low p-values suggest a high degree of confidence in the validity of this conclusion.

Critical Values

For this test, the critical value for a one-tailed test is **1.652**, and for a two-tailed test, it is **1.972**. Since the calculated t-statistic of **4.77** exceeds both critical values, the difference in mean scores between Comprehensive BIM Proficiency and Hybrid Tool Proficiency is statistically significant. This confirms that users perceive Comprehensive BIM Proficiency as superior, with the result being highly unlikely to be due to random variation.

The paired t-test results indicate a **statistically significant difference** between the mean scores of **Comprehensive BIM Proficiency** and **Hybrid Tool Proficiency** ($p<0.001$). The higher mean score for Comprehensive BIM Proficiency suggests that users perceive **BIM tools** as more proficient compared to a hybrid approach that combines traditional tools with partial BIM integration. The t-statistic ($t=4.77$) exceeding the critical values further confirms that this difference is not due to chance. Therefore, it can be concluded that **BIM as a comprehensive tool** offers superior proficiency, making it a preferred choice for enhancing performance and satisfaction in cost management and collaboration tasks.

4.8. Research Question Seven :

How does the use of 3D modeling compare to 2D methods in terms of efficiency and time savings for quantity takeoff processes in construction cost management?

Table 15 : Paired Sample t Test: (Quantity Take off)

	Quantity take off time 2D model	***Quantity take off time in 3D model***
Mean	10.77272727	2.977272727
Variance	6.374458874	1.868506494
Observations	22	22
Pearson Correlation	0.888394039	
Hypothesized Mean Difference	0	
df	21	
t Stat	25.16609271	
P(T<=t) one-tail	1.81348E-17	
t Critical one-tail	1.720742903	
P(T<=t) two-tail	3.62695E-17	
t Critical two-tail	2.079613845	

Hypotheses for One-Tailed Test

Null Hypothesis (H_0):

The mean quantity takeoff time using the 3D model is greater than or equal to the mean quantity takeoff time using the 2D method.

H0:μ_{3D} Model$\geq\mu_{2D}$ Method

Alternative Hypothesis (H_1):

The mean quantity takeoff time using the 3D model is less than the mean quantity takeoff time using the 2D method.

H1:μ_{3D} Model$<\mu_{2D}$ Method

Hypotheses for Two-Tailed Test

Null Hypothesis (H_0):

There is no significant difference in the mean quantity takeoff time between the 2D method and the 3D model.

H0:μ_{3D} Model$=\mu_{2D}$ Method

Alternative Hypothesis (H_1):

There is a significant difference in the mean quantity takeoff time between the 2D method and the 3D model.

H1:μ_{3D} Model $\neq \mu_{2D}$ Method

Interpretation

Mean Difference:

The mean quantity takeoff time for the 2D method is 10.77, while for the 3D model, it is 2.98. This indicates that, on average, the 3D model significantly reduces the time required for quantity takeoff compared to the 2D method. The observed difference suggests that 3D modeling offers a more efficient process for this task.

t-Statistic:

The calculated t-statistic is 25.17, which exceeds the critical values for both one-tailed (1.72) and two-tailed (2.08) tests. This high t-statistic reflects the substantial magnitude of the difference between the two methods, adjusted for sample size and variance, further confirming the statistical significance of the results.

p-Values:

The one-tailed p-value is 1.81×10^{-17}, and the two-tailed p-value is 3.63×10^{-17}, both of which are far below the standard significance level of 0.05. These extremely low p-values provide strong evidence to reject the null hypothesis, confirming that the observed difference in means is statistically significant and unlikely to be due to random chance.

Critical Values:

For this test, the critical value for the one-tailed test is 1.72, and for the two-tailed test, it is 2.08. Since the calculated t-statistic of 25.17 far exceeds both critical values, it can be concluded that the reduction in quantity takeoff time using the 3D model is statistically significant. The paired t-test results indicate a statistically significant reduction in quantity takeoff time when using the 3D model compared to the 2D method ($p<0.001$). The higher efficiency of the 3D model is demonstrated by the substantially lower mean time and the strong correlation between paired samples. The t-statistic ($t=25.17$) exceeding critical values reinforces the conclusion that this improvement is not due to chance. This finding highlights the effectiveness of 3D modeling technology in enhancing productivity and reducing time in construction quantity takeoff processes.

4.9. Research Question Eight :

How does the use of 3D modeling compare to 2D methods in terms of efficiency and time savings for quantity takeoff processes in construction cost management?

Table 16 : Regression Variable Names:

Sl.No	Statements used in the Questionnaire	Variable Names	Type
1	How accurate and time savings is your current tool in quantity take off process?	Accuracy and Time saving	Predictor
2	How effective is your current tool in tracking cost variations throughout the project lifecycle?	Tracking Cost	Predictor
3	Overall, how satisfied are you with the cost management features of your current tool?	Satisfaction of Current Tool	Dependent

4	How is the ability of your current collaboration tools to provide real-time updates on project costs?	Real_Time_Update	Predictor
5	How often do you experience miscommunication among stakeholders regarding cost management when using your current tools or methods?	Miscommunication Stakeholders	Predictor

Table 17 : Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.857a	0.735	0.73	0.564

The regression model explains **73.5%** of the variance in Satisfaction of Current Tool (**R^2=0.735**). The **Adjusted R^2=0.73** suggests a **strong fit**, indicating that the independent variables (Accuracy in Time Saving, Tracking Cost Variation, Project Cost Real-Time Update, and Miscommunication Among Stakeholders) collectively explain a substantial portion of the variability in the dependent variable. The Standard Error of Estimate (0.564) reflects the average distance that the observed values fall from the regression line.

Table 18 : Regression ANOVA :

Model	Sum of Squares		df	Mean Square	F	Sig.
1	Regression	205.306	4	51.327	161.269	.000
	Residual	74.156	233	0.318		
	Total	279.462	237			

The F-statistic (161.269) with a p-value < 0.001 indicates that the overall regression model is statistically significant. This suggests that at least one of the predictors is significantly associated with the satisfaction of the current tool.

Table 19 : Regression Coefficients :

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	**(Constant)**	-0.011	0.164		-0.067	0.947
	Accuracy_Time_Saving	0.26	0.059	0.221	4.441	0
	Tracking_Cost_Variation	0.341	0.058	0.317	5.839	0
	Project_Cost_Real_Time_Update	0.407	0.052	0.429	7.864	0
	Misscommunication_Stakeholders	-0.017	0.044	-0.016	-0.374	0.709
a Dependent Variable: Satisfaction_of_Current_Tool						

Accuracy in Time Saving:

Unstandardized Coefficient (B): 0.26

Standardized Coefficient (Beta): 0.221

$t = 4.441$, $p < 0.001$

This indicates that for every 1-unit increase in time-saving accuracy, the satisfaction score increases by 0.26 units. The effect is significant, and time-saving accuracy has a moderate positive influence on satisfaction.

Tracking Cost Variation:

Unstandardized Coefficient (B): 0.341

Standardized Coefficient (Beta): 0.317

$t = 5.839$, $p < 0.001$

For every 1-unit increase in the ability to track cost variations, the satisfaction score increases by 0.341 units. This predictor has a significant and moderately strong positive impact on satisfaction.

Project Cost Real-Time Update:

Unstandardized Coefficient (B): 0.407

Standardized Coefficient (Beta): 0.429

t = 7.864, p < 0.001

This variable has the strongest positive effect on satisfaction. For every 1-unit improvement in real-time updates, the satisfaction score increases by 0.407 units. It is a highly significant and impactful predictor.

<u>Miscommunication Among Stakeholders:</u>

Unstandardized Coefficient (B): -0.017

Standardized Coefficient (Beta): -0.016

t = -0.374, p = 0.709

This variable is not significant, indicating that miscommunication among stakeholders does not have a meaningful impact on satisfaction in this model.

The regression model is statistically significant, explaining a substantial proportion of the variability in **Satisfaction of Current Tool** (R^2=0.735). Among the predictors, **Project Cost Real-Time Update** has the strongest positive influence on satisfaction, followed by **Tracking Cost Variation** and **Accuracy in Time Saving**. **Miscommunication Among Stakeholders** does not significantly affect satisfaction. This highlights the importance of real-time project updates and accurate cost management in improving user satisfaction with the current tools.

4.10 Summary of Findings

The study comprehensively explores the impact of digitalization in construction cost management, emphasizing Building Information Modeling (BIM) and its comparison with traditional tools like AutoCAD. The findings highlight critical aspects such as tool efficiency, user satisfaction, barriers to adoption, and future implications. Below are the major findings in detail:

Efficiency Gains Through BIM Tools

One of the most significant findings is the substantial efficiency gains achieved through BIM adoption compared to traditional methods like AutoCAD. BIM's automated processes for quantity take-offs, clash detection, and real-time updates drastically reduce the time and effort required for cost management tasks.

Time-Saving in Quantity Take-Offs: BIM's automation reduced the mean time for quantity take-offs to 2.98 hours, compared to 10.77 hours for traditional 2D methods. This represents a 72% reduction in time, underscoring BIM's capacity to streamline processes.

Error Reduction: BIM's integrated design and cost estimation processes minimize errors that are common in manual workflows. Automated clash detection ensures that potential design conflicts are identified early, preventing costly on-site rework.

Impact on Workflow: These efficiencies enable project teams to allocate more time to strategic tasks, improving overall project timelines and cost control.

These findings validate BIM's superiority in ensuring accurate, efficient, and streamlined construction cost management, confirming its potential to address long-standing industry inefficiencies.

Enhanced Accuracy and Real-Time Collaboration

BIM emerged as a significant enabler of accuracy and real-time collaboration, addressing critical challenges faced by traditional tools.

Accuracy in Cost Estimation: The Chi-Square analysis revealed that BIM significantly outperforms AutoCAD in accuracy ($p < 0.001$). Users rated BIM tools higher in the "Highly Accurate" category, indicating their trust in its precision.

Real-Time Updates: Regression analysis identified real-time project updates as the strongest predictor of user satisfaction ($\beta = 0.429$, $p < 0.001$). BIM's ability to synchronize project data dynamically ensures that all stakeholders are aligned with the latest developments.

Improved Stakeholder Communication: By centralizing project data and facilitating transparent information sharing, BIM reduces instances of miscommunication, a major issue in traditional workflows. Stakeholders using BIM reported significantly fewer communication errors compared to those using AutoCAD.

These findings emphasize BIM's potential to enhance collaboration, mitigate risks associated with outdated information, and improve decision-making processes.

User Satisfaction with Digital Tools

The study found a direct relationship between the use of advanced digital tools and user satisfaction.

Satisfaction Levels: Users of BIM tools reported higher satisfaction scores compared to AutoCAD users. The satisfaction was strongly influenced by features like real-time updates, cost tracking, and automated reporting.

Predictors of Satisfaction: The regression model explained 73.5% of the variance in satisfaction ($R^2 = 0.735$). The key predictors were real-time updates ($\beta = 0.429$, $p < 0.001$), cost tracking ($\beta = 0.317$, $p < 0.001$), and time-saving accuracy ($\beta = 0.221$, $p < 0.001$).

Role of Proficiency: The paired t-test comparing Comprehensive BIM Proficiency and Hybrid Tool Proficiency revealed that users with access to fully integrated BIM tools had significantly higher proficiency scores ($t = 4.77$, $p < 0.001$). This indicates that comprehensive digital adoption enhances user confidence and satisfaction.

These findings underline the importance of integrating advanced features and providing adequate training to ensure user satisfaction and maximize the benefits of digital tools.

Barriers to Adoption

Despite its advantages, the study identifies several barriers that hinder the widespread adoption of BIM tools.

High Implementation Costs: The initial investment required for BIM adoption—including software licenses, hardware upgrades, and training—remains a significant barrier, particularly for small and medium-sized enterprises (SMEs).

Cultural Resistance: Many firms continue to rely on traditional tools like AutoCAD due to resistance to change. This reluctance is often driven by a lack of understanding of BIM's long-term benefits.

Skill Gaps: A notable finding was the lack of technical expertise among mid-level and senior professionals, creating reliance on external consultants and increasing project costs.

While younger professionals entering the workforce are more proficient in digital tools, there is a significant gap in digital literacy among experienced professionals.

Addressing these barriers through targeted policy interventions, financial incentives, and capacity-building initiatives is crucial to accelerating digital adoption.

Comparative Analysis of BIM and Traditional Tools

The comparative analysis highlights the advantages of BIM over traditional tools in critical areas:

Proficiency and Workflow Integration: BIM users scored higher on proficiency, reflecting the advantages of an integrated approach to design and cost management. Hybrid systems, combining traditional tools with partial digital adoption, showed lower efficiency and satisfaction scores.

Stakeholder Coordination: BIM's integrated platform reduces fragmentation in communication, a persistent issue with traditional methods. By offering a single source of truth, BIM fosters better alignment among project teams.

Sustainability and Lifecycle Management: BIM tools enable detailed planning for sustainability goals, such as energy efficiency and waste reduction, aligning with global environmental standards.

These comparisons illustrate BIM's transformative impact, not only in addressing immediate inefficiencies but also in laying the groundwork for future advancements in construction workflows.

Future Implications and Strategic Insights

The study's findings have significant implications for the future of construction cost management and the broader industry.

Driving Sustainability: BIM's capabilities in lifecycle management and energy modeling can help achieve long-term sustainability goals. By simulating a building's performance over its lifecycle, BIM supports better decision-making and resource optimization.

Integration with Emerging Technologies: The integration of BIM with IoT, AI, and blockchain presents exciting possibilities. For example, IoT sensors can provide real-time data for BIM models, enhancing monitoring and predictive maintenance.

Supporting SMEs: Encouraging BIM adoption among SMEs requires tailored solutions, such as open-source tools, tiered pricing models, and government subsidies. These measures can lower financial barriers and ensure equitable digital transformation.

These insights underscore the need for strategic investments in digital tools and policies that foster collaboration, innovation, and sustainability.

The major findings of this study highlight BIM's transformative potential in construction cost management, providing compelling evidence of its efficiency, accuracy, and collaborative advantages. However, addressing barriers to adoption and equipping the workforce with the necessary skills will be critical to unlocking its full potential. These findings offer a roadmap for stakeholders to leverage digital tools for improved project outcomes and sustainable industry growth.

4.11 Conclusion

The data analysis conducted in this study provides comprehensive insights into the role of digitalization in construction cost management. By employing both descriptive and inferential statistical methods, the analysis highlights critical patterns, relationships, and differences among variables related to tool usage, efficiency, satisfaction, and performance. The descriptive statistics reveal a balanced gender representation and a predominance of younger professionals with 0-5 years of experience, indicating the perspectives of a digitally inclined workforce. AutoCAD with MS Office emerges as the most commonly used tool, but BIM with MS Office demonstrates significant potential in terms of accuracy, time-saving, and stakeholder coordination, as indicated by the Chi-Square tests.

Inferential analyses further validate the advantages of BIM tools over traditional methods. Significant associations were identified between BIM tool usage and higher accuracy, better cost variation tracking, improved satisfaction, and fewer instances of stakeholder miscommunication. Regression analysis underscores the importance of real-time project cost updates and tracking cost variations as key predictors of satisfaction, with BIM tools consistently outperforming AutoCAD in these areas. Paired t-tests confirm that BIM-based 3D modeling significantly reduces quantity take-off time compared to 2D methods, highlighting its efficiency and reliability. The findings establish that digital tools, particularly BIM, provide enhanced precision, efficiency, and collaboration in construction cost management. This evidence supports the broader adoption of BIM tools to address industry challenges and improve project outcomes. The analysis also provides actionable insights for decision-makers, emphasizing the need to prioritize real-time updates, training, and integration of advanced digital tools to maximize their benefits.

CHAPTER V:

DISCUSSION

5.1 Discussion of Results

The findings of this study strongly support the transformative potential of digitalization in construction cost management, particularly through the adoption of Building Information Modeling (BIM). By systematically analyzing quantitative data and exploring the practical application of digital tools, this research aligns with existing literature emphasizing BIM's superiority in enhancing accuracy, efficiency, and real-time collaboration. The discussion below elaborates on the key findings and situates them within broader industry trends and challenges, while also offering insights into the implications for future practices.

5.1.1 Adoption and Efficiency Gains

One of the most significant findings from this study is the marked improvement in accuracy and efficiency associated with BIM tools. Compared to traditional methods such as AutoCAD, BIM consistently outperforms across critical dimensions, including quantity take-offs, real-time cost updates, and stakeholder coordination. These advantages are not only statistically validated but also resonate with broader industry observations.

A) Addressing Long-Standing Industry Challenges

The construction industry has historically faced challenges related to inaccuracies in cost estimation, inefficient workflows, and high rates of rework due to design errors. BIM directly addresses these issues by integrating design, scheduling, and cost estimation into a unified platform. Automated processes like quantity take-offs significantly reduce manual errors, corroborating findings by Eastman et al. (2011), who identified BIM's capacity to streamline cost estimation as a cornerstone of its value proposition. For instance, the mean time required for quantity take-offs using 3D models in BIM (2.98 hours) was significantly lower than for 2D CAD models (10.77 hours), highlighting the efficiency gains enabled by automation.

B) Real-Time Collaboration and Updates

Another transformative feature of BIM is its ability to provide real-time project updates. This study's regression analysis revealed that real-time project updates were the strongest predictor of user satisfaction ($\beta = 0.429$, $p < 0.001$). This finding underscores the importance of dynamic and integrated project management workflows. Unlike traditional tools, which often require manual adjustments and coordination across disparate systems, BIM centralizes project data. This reduces delays, ensures consistency, and improves overall project transparency.

C) Cost Implications

Efficiency gains also translate into tangible cost savings. By automating repetitive tasks and reducing errors, BIM minimizes project delays and rework costs. For example, automated clash detection ensures that design inconsistencies are resolved during the planning phase, rather than on-site. These efficiencies align with findings from Azhar et al. (2012), who noted that BIM's ability to reduce change orders can save up to 10% of project costs.

5.1.2. Barriers to Adoption

While the advantages of BIM are evident, the study also highlights persistent barriers to its widespread adoption. Despite its proven benefits, many firms, particularly small and medium-sized enterprises (SMEs), continue to rely on traditional tools like AutoCAD. The reasons for this reluctance are multifaceted and deeply rooted in the industry's structure and culture.

A) High Implementation Costs

The initial investment required to adopt BIM can be prohibitively high for smaller firms. These costs include not only software licenses but also the hardware upgrades needed to support resource-intensive BIM applications. Additionally, implementing BIM often requires significant process overhauls, which can disrupt ongoing projects and add to indirect costs. These findings align with Kushwaha (2016), who identified cost as a primary barrier to digital transformation in construction.

B) Resistance to Change

Cultural resistance within organizations further exacerbates the adoption gap. Many firms are hesitant to deviate from established practices, particularly if their current methods are perceived as "good enough." This inertia is often driven by a lack of understanding of BIM's long-term benefits and the risks associated with traditional workflows. Leadership buy-in is critical to overcoming this resistance, as top-down support can drive organizational change and encourage innovation.

C) Skill Gaps

The lack of technical expertise among construction professionals is another significant barrier. While younger professionals entering the workforce may have exposure to BIM tools, mid-level and senior professionals often lack the necessary skills to fully leverage these technologies. This skill gap creates a reliance on external consultants, further increasing costs and limiting the internal capacity to manage BIM projects. Addressing this gap through targeted training and education programs is essential for fostering a digitally competent workforce.

5.1.3. Stakeholder Collaboration

One of BIM's most transformative aspects is its ability to enhance collaboration among project stakeholders. This study's findings indicate that BIM reduces instances of miscommunication and fosters more effective coordination, a critical improvement over traditional method.

A) Integrated Platforms

BIM's integrated platform serves as a "single source of truth," enabling seamless data sharing among architects, engineers, contractors, and clients. Real-time updates ensure that all stakeholders have access to the latest project information, reducing discrepancies and improving decision-making. These benefits are particularly evident in complex projects with multiple interdependent systems, where traditional workflows often struggle to maintain consistency.

B) Reducing Miscommunication

The Chi-Square test results reveal a significant reduction in miscommunication among stakeholders using BIM tools. The study found that BIM users reported fewer instances of miscommunication (categorized as "Rarely" or "Never"), while AutoCAD users frequently experienced communication issues. This aligns with findings by Azhar et al. (2012), who identified improved communication as one of BIM's key contributions to project success.

C) Enhancing Accountability

By providing a transparent and collaborative environment, BIM also enhances accountability among stakeholders. Features like audit trails and version control ensure that changes are well-documented and traceable, reducing conflicts and improving trust among project participants. This fosters a more collaborative culture, where stakeholders work towards common goals rather than operating in silos.

The findings of this study underscore the transformative potential of digitalization in construction cost management, with BIM emerging as a critical enabler of efficiency, accuracy, and collaboration. By addressing the barriers to adoption and leveraging BIM's advanced capabilities, the construction industry can achieve significant improvements in project outcomes and sustainability. These insights provide a roadmap for policymakers, industry leaders, and practitioners to drive digital transformation, ensuring a more innovative, equitable, and sustainable future for the construction sector.

5.2. Theoretical Connections to Results

Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) proposed by Davis (1989) suggests that two key factors influence the adoption of technology: perceived usefulness (PU) and perceived ease of use (PEOU). The results showing that BIM tools (or advanced digital tools) significantly improve accuracy, time savings, and real-time updates align closely with the PU factor of TAM. Respondents indicated that digital tools were more effective in tracking cost variations and minimizing miscommunication, which enhances their perceived usefulness. Additionally, the superior user satisfaction with advanced tools highlights the importance of ease of use, suggesting that intuitive design and automation in digital platforms reduce the learning curve.

Connection to Results:

The regression analysis in the study indicates that real-time cost updates and tracking cost variations are significant predictors of user satisfaction. This strongly supports the TAM framework, where users adopt technology primarily based on its ability to improve their workflow and productivity.

Broader Implication:

For the construction sector, TAM highlights that organizations must focus on improving both the usability and perceived benefits of digital tools through training and intuitive design to drive widespread adoption.

Diffusion of Innovation (DOI) Theory

Rogers' Diffusion of Innovation (DOI) Theory (1962) describes how innovations are adopted in an industry based on five attributes: relative advantage, compatibility, complexity, trialability, and observability. The significant advantages offered by digital tools in terms of accuracy, time savings, and cost management align well with the concept of **relative advantage**, as shown in your findings. However, the study also highlights barriers such as resistance to change and skill gaps, which correspond to the **complexity** attribute in DOI.

Connection to Results:

The results showing higher satisfaction and accuracy with advanced tools (like BIM with MS Office) compared to traditional tools demonstrate the relative advantage of adopting these innovations.

The challenges noted, such as miscommunication and limitations in tool proficiency among small-scale stakeholders, reflect concerns about compatibility and complexity, which slow adoption.

Broader Implication:

To accelerate digital adoption, companies should focus on trialability (pilot projects) and observability (showcasing successful case studies) to demonstrate measurable benefits to skeptical stakeholders.

Resource-Based View (RBV) of the Firm

The Resource-Based View (RBV), introduced by Barney (1991), posits that organizations achieve a competitive advantage by leveraging unique, valuable, and inimitable resources. The findings underscore the role of digital tools as strategic resources that enhance accuracy, streamline cost management, and improve stakeholder coordination—elements critical for achieving competitive differentiation in the construction industry.

Connection to Results:

The results show that advanced digital tools outperform traditional tools across metrics such as time efficiency, cost tracking, and real-time updates, indicating their value as strategic resources. Companies that integrate these tools can achieve significant process improvements and competitive advantages.

Broader Implication:

Construction firms must treat digital tools not as optional solutions but as essential resources for enhancing productivity, reducing errors, and achieving cost efficiencies. Proper investment in training and implementation further strengthens the firm's competitive position.

Lean Construction Theory

Lean construction, derived from Lean Manufacturing principles, focuses on minimizing waste and maximizing value through process optimization. The results showing reduced miscommunication, enhanced cost accuracy, and improved efficiency through digital tools align with Lean Construction principles, particularly the elimination of **non-value-adding activities** such as manual cost tracking and inefficient communication.

Connection to Results:

The Chi-Square results showing significant associations between tool type and reduced miscommunication align with Lean principles that emphasize improved collaboration and workflow efficiency. The significant reduction in quantity take-off time with 3D models compared to 2D methods highlights the Lean principle of removing process delays and improving productivity.

Broader Implication:

Adopting digital tools enables Lean practices by automating repetitive tasks, enhancing stakeholder collaboration, and improving cost accuracy—ultimately driving value for both clients and firms.

Systems Theory

Systems Theory, developed by Bertalanffy (1968), views organizations and projects as complex systems with interdependent components. The findings related to stakeholder coordination and real-time updates emphasize the importance of systems thinking in construction projects. Digital tools such as BIM act as integrative platforms, enhancing communication, collaboration, and alignment among all project stakeholders.

Connection to Results:

The findings highlight that advanced tools improve coordination by reducing miscommunication and offering real-time updates. This aligns with the Systems Theory perspective, where improved information flow leads to enhanced performance of the entire system.

Broader Implication:

Construction organizations must adopt systems-thinking approaches by integrating digital tools into their workflows to ensure seamless collaboration, improve decision-making, and minimize project delays.

Triple Constraint Theory

The Triple Constraint Theory, which considers cost, time, and quality as critical constraints in project management, is highly relevant to your findings. Your study highlights that digital tools significantly improve accuracy (quality), reduce time for tasks like quantity take-offs, and enhance cost tracking—all directly linked to the triple constraints of project success.

Connection to Results:

The findings from t-tests show substantial time savings when using advanced tools (e.g., 3D models compared to 2D methods).

Improved cost tracking and accuracy further demonstrate how digital tools address the cost and quality dimensions of the triple constraints.

Broader Implication:

Digital tools must be prioritized as essential components of project management frameworks to balance the constraints of cost, time, and quality in construction projects.

Summary of Theoretical Integration

By aligning your results with established theories—such as the **Technology Acceptance Model**, **Diffusion of Innovation**, and **Lean Construction**—it becomes evident that digital tools significantly enhance construction cost management processes. These tools offer measurable benefits in terms of accuracy, time savings, cost tracking, and stakeholder coordination while addressing project constraints and resource challenges. However, barriers like complexity, skill gaps, and resistance to change align with theoretical insights that highlight the need for organizational commitment and structured implementation strategies. By connecting the findings to these established theories, the discussion section not only demonstrates the practical relevance of digital tools but also positions your research within a robust theoretical framework, strengthening its academic rigor and impact.

5.3: Future Research Direction

Future research in the realm of digitalization within construction cost management can address several critical gaps identified in this study. One key area for exploration is the integration of advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), and Blockchain, which hold significant potential to automate processes, enhance predictive cost analysis, and improve real-time decision-making. Further research could examine the extent to which these technologies contribute to increased cost control efficiency and accuracy while overcoming existing barriers to adoption. Additionally, longitudinal studies are necessary to investigate the long-term impacts of digital tools on cost savings, project timelines, and user satisfaction. By tracking projects over extended durations, researchers can identify trends and evaluate the sustainability of digital adoption. Comparative studies across diverse geographies and economic contexts would also be valuable in understanding how cultural, regulatory, and economic differences influence the implementation and success of digital tools. These insights could help tailor strategies for global adoption, particularly in developing regions. Another promising direction is the study of small and medium-sized enterprises (SMEs), which often face unique financial, operational, and resource-related challenges in adopting digital tools. Research could focus on designing affordable and scalable solutions to foster widespread adoption within SMEs. Furthermore, future work could explore how digital tools support sustainability goals through life cycle costing and energy-efficient modeling, enabling the construction sector to align with global environmental priorities. In parallel, behavioral studies using frameworks like the Technology Acceptance Model (TAM) and Diffusion of Innovation (DOI) could shed light on the psychological and organizational factors influencing professionals' willingness to adopt digital tools, addressing concerns such as resistance to change and skill gaps.

The interoperability of digital tools remains a critical challenge, and future studies could develop frameworks for enhancing compatibility and standardization between software systems. This would streamline collaboration, reduce redundancies, and promote seamless data exchange among stakeholders. Research on real-time data integration and analytics can further highlight how live site data, combined with advanced analytics, improves cost tracking, minimizes delays, and enhances decision-making processes. Detailed case studies showcasing successful implementation of digital tools across various project types and scales would provide practical insights and best practices, offering a roadmap for organizations navigating digital transformation. Lastly, examining the role of government policies, regulatory frameworks, and financial incentives in driving digital adoption is essential for creating an ecosystem that supports innovation. By addressing these areas, future research can contribute to the development of a more robust, efficient, and sustainable construction cost management system, positioning the construction industry to fully leverage digital technologies in the evolving digital economy.

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

The research delves into the critical role of digitalization, with a specific focus on Building Information Modeling (BIM), in transforming cost management practices within the construction industry. The research underscores the limitations of traditional tools like AutoCAD, which often lead to inefficiencies, miscommunication, and cost overruns during project execution. In contrast, BIM emerges as a comprehensive solution that integrates design, cost estimation, scheduling, and project lifecycle management into a single platform, significantly improving accuracy, efficiency, and stakeholder collaboration. By facilitating real-time project updates and automating complex processes like quantity take-offs and clash detection, BIM addresses long-standing challenges in the construction sector.

The study employs a robust methodology, combining quantitative and qualitative approaches to analyze the adoption and effectiveness of digital tools. Statistical analyses such as Chi-Square tests and t-tests reveal significant associations between tool types and key performance metrics, including accuracy, time savings, cost tracking, and user satisfaction. Regression analysis further highlights the importance of features like real-time project cost updates and effective cost variation tracking in driving user satisfaction, while demonstrating BIM's superior performance compared to hybrid tools.

The findings emphasize that while BIM is associated with higher proficiency, efficiency, and stakeholder coordination, its adoption faces barriers such as high implementation costs, resistance to change, and insufficient technical expertise within the industry. The study identifies critical strategies to overcome these obstacles, including targeted training, policy incentives, and the development of standardized frameworks for interoperability and data management.

The research contributes significantly to construction economics by demonstrating the transformative potential of BIM in cost management. It also explores the broader implications of digitalization, including its role in fostering sustainability through lifecycle cost analysis and energy modeling. By providing actionable insights into the practical implementation of BIM and other digital tools, the study not only validates their value in contemporary construction projects but also lays the groundwork for future advancements in the field. The research concludes with policy recommendations and a call for industry-wide collaboration to ensure the widespread adoption of digital solutions, driving innovation, efficiency, and sustainability in the construction sector.

6.2 Implications

The findings of this study extend beyond immediate benefits, highlighting BIM's potential to drive long-term improvements in sustainability, lifecycle management, and equitable access to digital tools.

A) Driving Sustainability

BIM's integration with 6D modeling enables detailed planning for sustainability objectives, including energy efficiency and waste reduction. By simulating a building's performance over its lifecycle, BIM helps architects and engineers make informed decisions about materials, energy systems, and construction methods. These capabilities align with global efforts to achieve sustainable development goals (SDGs), particularly in reducing carbon emissions and promoting resource efficiency.

B) Enhancing Lifecycle Cost Management

BIM's ability to provide a comprehensive view of a project's lifecycle—from design and construction to operation and maintenance—offers significant advantages for long-term cost management. Features like predictive maintenance scheduling and asset tracking ensure that buildings remain functional and cost-efficient throughout their lifespan. These capabilities not only reduce operational costs but also enhance asset value, making BIM a valuable tool for owners and facility managers.

C) Tailored Solutions for SMEs

Encouraging the adoption of BIM among SMEs will require targeted interventions to mitigate cost and complexity. Open-source BIM tools, tiered pricing models, and government subsidies can help lower financial barriers, while industry associations can provide training and support. Collaborative initiatives, such as shared BIM resources or regional centers of excellence, can also enable smaller firms to benefit from digital transformation without bearing the full costs independently.

D) Integration with Emerging Technologies

The integration of BIM with emerging technologies like IoT, AI, and blockchain presents exciting possibilities for the future of construction. IoT sensors can feed real-time data into BIM models, enhancing monitoring and decision-making. AI algorithms can analyze historical data to optimize designs and predict potential risks, while blockchain can ensure secure and transparent data sharing. These synergies have the potential to redefine construction workflows, making them more intelligent and adaptive.

6.3 Recommendations for Future Research

The adoption of digital solutions in the construction industry has transformative potential to enhance efficiency, reduce costs, and improve project outcomes. However, widespread adoption requires a multi-faceted approach involving supportive policies, incentives, and capacity building. Below are detailed policy recommendations to encourage the integration of digital technologies in the construction sector.

Develop a National Digital Construction Strategy

A national digital construction strategy is essential to provide a clear framework for the construction industry’s transition towards digitalization. This strategy should outline measurable goals for digital adoption, such as achieving a specific percentage of BIM implementation in public and private projects within a defined timeframe. By developing and disseminating standardized guidelines, such as those aligned with ISO 19650 and BS 1192, the strategy would ensure consistency and interoperability across the industry. It should foster collaboration through public-private partnerships (PPPs), encouraging government bodies, private companies, and technology providers to co-develop innovative solutions and pilot projects. Additionally, an independent monitoring body should be established to track progress, identify challenges, and recommend improvements. This comprehensive strategy will serve as a roadmap, aligning stakeholders and resources towards achieving digital transformation in the construction sector.

Provide Financial Incentives

Financial constraints are one of the primary barriers to adopting advanced digital tools in the construction industry. Governments and industry organizations can address this challenge by offering targeted financial incentives. Subsidies and grants should be provided to small and medium-sized enterprises (SMEs) to offset the initial costs of purchasing software like BIM and investing in supporting hardware. Tax incentives can further encourage firms to adopt digital tools and invest in workforce training. Additionally, allocating funds for research and development (R&D) can drive innovation in developing cost-effective digital solutions tailored to local industry needs. These financial mechanisms will reduce the burden on construction firms, particularly smaller ones, making digital tools more accessible and encouraging widespread adoption.

Strengthen Capacity Building and Training

The successful adoption of digital tools requires a workforce equipped with the necessary skills to use them effectively. Policies should focus on integrating digital construction technologies into university curriculums and vocational training programs. For professionals already in the workforce, continuous professional development (CPD) programs should be mandated, with training sessions designed to improve proficiency in tools like BIM, 3D modeling, and cloud-based platforms. Government-backed certification programs can standardize skill levels and ensure recognition across the industry. Knowledge-sharing platforms should also be established to facilitate the exchange of best practices, case studies, and lessons learned. These capacity-building initiatives will empower the workforce, ensuring that professionals across all levels are prepared for a digitally-driven construction environment.

Promote Regulatory Compliance

Regulatory policies can drive digital adoption by mandating the use of digital tools in certain projects. Governments should require the use of BIM for public infrastructure projects to set an example and demonstrate the benefits of digitalization. Regulations should also enforce data governance standards, ensuring secure and consistent sharing of information among stakeholders. Transitioning to digital platforms for project approvals can streamline workflows and encourage compliance with digital standards. These regulatory measures will not only create a structured environment for digital adoption but also incentivize private sector firms to follow suit, establishing digital tools as a norm rather than an option in construction practices.

Foster Technology Accessibility

Accessibility to digital tools is a critical factor in ensuring equitable adoption across the construction industry. Policies should encourage technology providers to offer tiered pricing models, making software affordable for smaller firms. Governments and industry bodies can also subsidize or develop open-source digital tools to lower entry barriers for resource-constrained organizations. Promoting cloud-based solutions is another key aspect, as these platforms reduce the need for expensive hardware and facilitate collaboration among geographically dispersed teams. By making technology more accessible, these measures will enable even smaller players in the construction industry to leverage digital tools and compete effectively.

Encourage Pilot Projects and Demonstrations

Pilot projects serve as a practical demonstration of the benefits of digital solutions in real-world scenarios. Governments and industry associations should fund flagship projects to showcase the efficiency, accuracy, and cost-effectiveness of digital tools like BIM. Case studies documenting these projects should be widely disseminated to highlight measurable outcomes such as reduced timelines, cost savings, and improved stakeholder coordination. Establishing innovation hubs where new technologies can be tested and refined will further promote confidence in digital tools. By demonstrating tangible benefits through pilot projects, these initiatives will build trust and encourage reluctant firms to embrace digitalization.

Promote Collaboration and Industry-Wide Integration

Collaboration across the construction value chain is vital for successful digital adoption. Policies should focus on developing standardized data exchange protocols to ensure seamless interoperability among various digital tools and platforms. Stakeholder workshops and forums can be organized to align architects, engineers, contractors, and clients on digital transformation goals and practices. Incentivizing collaborative ventures among firms can facilitate resource-sharing and expertise development in adopting digital tools. These collaborative frameworks will foster a cohesive industry-wide approach, ensuring that all stakeholders are aligned and contributing towards a common goal of digital integration.

Encourage Sustainable Construction

Digital solutions play a critical role in promoting sustainability in the construction industry. Governments should incentivize the use of tools that track and minimize carbon emissions during construction. Lifecycle management tools integrated with digital platforms can ensure that projects meet environmental standards throughout their lifecycle. Policies should also tie digital adoption to achieving green building certifications, encouraging firms to integrate sustainable practices into their workflows. By linking digitalization with sustainability goals, these measures will align environmental and technological advancements, driving the industry towards a more sustainable future.

6.4. Conclusion

The research comprehensively examines the transformative role of digitalization in construction cost management, providing an in-depth analysis of its impact on efficiency, accuracy, and stakeholder collaboration. By employing a robust methodological framework that integrates quantitative data analysis, real-world process implementation, and an extensive review of existing literature, the research delivers a holistic understanding of the opportunities and challenges associated with adopting digital tools in the construction sector.

The findings reveal that digital solutions, particularly Building Information Modeling (BIM), significantly enhance the efficiency and accuracy of construction cost management practices compared to traditional tools like AutoCAD. BIM stands out as a superior technology in multiple dimensions, including its ability to facilitate real-time project cost updates, streamline quantity take-off processes, and improve overall stakeholder coordination. These capabilities are underscored by statistical analyses, including Chi-square tests and paired t-tests, which consistently demonstrate that BIM tools save time, reduce errors, and offer higher user satisfaction. For instance, the mean time required for quantity take-offs using 3D models was significantly lower than that for 2D CAD models, reinforcing the efficiency gains enabled by BIM. Furthermore, regression analysis highlights that real-time project updates and cost variation tracking are the strongest predictors of user satisfaction, demonstrating the critical importance of these features in digital tools.

On the other hand, traditional tools like AutoCAD exhibit notable limitations, particularly in managing cost variations, reducing miscommunication, and ensuring stakeholder alignment. These shortcomings highlight the growing need for the industry to transition from manual and semi-digital methods to fully digital solutions. The data further reveals that user satisfaction is significantly higher among those using BIM tools, with dissatisfaction levels notably higher among AutoCAD users. This finding underscores the necessity of integrating advanced tools to meet the evolving demands of construction projects.

The study identifies several barriers to the widespread adoption of digital solutions, including financial constraints, lack of technical skills, and cultural resistance to change within the industry. These challenges are particularly pronounced for small and medium-sized enterprises (SMEs), which often struggle with the high costs associated with purchasing and implementing advanced digital tools. Additionally, the workforce's lack of proficiency in digital technologies and the reluctance of leadership to embrace change further hinder the adoption process. These barriers provide a strong basis for the policy recommendations offered in this thesis.

The proposed policy recommendations aim to address these barriers comprehensively and promote the adoption of digital solutions across the construction sector. Key recommendations include the development of a national digital construction strategy, financial incentives such as subsidies and tax breaks, and robust capacity-building initiatives. Integrating digital construction technologies into educational curriculums, coupled with continuous professional development programs, is essential for creating a skilled workforce capable of leveraging digital tools effectively. Regulatory measures, such as mandating BIM for public projects, will also play a critical role in setting benchmarks for digital adoption. Furthermore, fostering collaboration among stakeholders and ensuring accessibility to affordable technologies will help create a more inclusive and innovation-driven construction ecosystem.

From a theoretical perspective, this research contributes to the existing body of knowledge by providing empirical evidence on the comparative advantages of digital tools like BIM over traditional methods. It also fills critical gaps in understanding the practical benefits of digitalization in cost management, offering a data-driven foundation for future research in this domain. The insights derived from this study have practical implications for policymakers, industry leaders, and academic institutions. Construction firms are encouraged to invest in digital tools and training programs to stay competitive and maximize their operational efficiency. Policymakers must create a supportive environment that facilitates digital adoption through financial support, regulatory frameworks, and strategic initiatives. Educational institutions need to align their curriculums with industry requirements, equipping students and professionals with the skills needed to thrive in a digitally-driven construction landscape.

The findings emphasize the potential of digitalization to address broader challenges within the construction industry, including sustainability and resource efficiency. Digital tools enable more accurate project planning and lifecycle management, which can significantly reduce waste and improve environmental outcomes. Integrating digital solutions into sustainability initiatives will further enhance their value, aligning industry practices with global efforts to achieve sustainable development goals.

Hence, this study underscores the transformative potential of digitalization in revolutionizing construction cost management. By addressing key challenges and providing actionable recommendations, the research lays a solid foundation for the construction industry to embrace innovation and digital transformation. The adoption of advanced tools like BIM has the potential to redefine industry standards, offering unparalleled efficiency, precision, and stakeholder satisfaction. As the construction sector evolves to meet the demands of the modern era, the insights from this study serve as a roadmap for driving digital integration, fostering collaboration, and ensuring sustainable growth. This research is not only a call to action but also a guiding framework for a future where digital technologies are central to the success of construction projects worldwide.

REFERENCES

- Arias, J., Törmä, S., Carro, M., & Gupta, G. (2022). Building information modeling using constraint logic programming. *Theory and Practice of Logic Programming*.
- Igwe, U. S., Mohamed, S. F., & Azwarie, M. B. M. D. (2022). Acceptance of contemporary technologies for cost management of construction projects. *Journal of Information Technology in Construction (ITcon)*, 27, 864-883.
- Vycital, M., & Jarský, C. (2020). An automated nD model creation on BIM models. *Organization, Technology and Management in Construction*, 11, 2218–2231.
- Afsari, K., Florez, L., Maneke, E., & Afkhamiaghda, M. (2019). An experimental investigation of the integration of smart building components with Building Information Model (BIM). *36th International Symposium on Automation and Robotics in Construction (ISARC 2019)*.
- Barreiro, A. C., Trzeciakiewicz, M., Hilsmann, A., & Eisert, P. (2023). Automatic reconstruction of semantic 3D models from 2D floor plans. *36th International Symposium on Automation and Robotics in Construction (ISARC 2023)*.
- Azhar, S. (2011). Building Information Modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, 11(3), 241-252.
- Sepasgozar, S. M. E., Costin, A. M., Karimi, R., Shirowzhan, S., Abbasian, E., & Li, J. (2022). BIM and digital tools for state-of-the-art construction cost management. *Buildings*, 12(4), 396.
- Ibrahim, A., Sabet, A., & Golparvar-Fard, M. (2019). BIM-driven mission planning and navigation for automatic indoor construction progress detection using robotic ground platform. *2019 European Conference on Computing in Construction*, Chania, Crete, Greece.
- Barki, H., Fadli, F., Shaat, A., Boguslawski, P., & Mahdjoubi, L. (2015). BIM models generation from 2D CAD drawings and 3D scans: An analysis of challenges and

opportunities for AEC practitioners. *WIT Transactions on The Built Environment*, 149, 369-380.

- Svetel, I., Jarić, M., & Budimir, N. (2014). BIM: Promises and reality. *SPATIUM International Review*, 32, 34-38.
- Kocakaya, M. N., Namlı, E., & Işıkdağ, Ü. (2019). Building Information Management (BIM), a new approach to project management. *Journal of Sustainable Construction Materials and Technologies*, 4(1), 323–332.
- Pandya, P. U., & Koehn, E. E. (2009). Building information modeling and sustainability. *Proceedings of the 2009 ASEE Gulf-Southwest Annual Conference*. Baylor University.
- Glema, A. (2017). Building Information Modeling (BIM): Level of digital construction. *Poznan University of Technology*.
- Moller, N. L. H., & Bansler, J. P. (2017). Building Information Modeling: The dream of perfect information. *Proceedings of the 15th European Conference on Computer-Supported Cooperative Work*, European Society for Socially Embedded Technologies.
- Gray, M., Gray, J., Teo, M., Chi, S., & Cheung, F. (2012). Building Information Modeling: An international survey. *Proceedings of the 2012 ASEE Gulf-Southwest Annual Conference*.
- Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building Information Modeling (BIM): Now and beyond. *Australasian Journal of Construction Economics and Building*, 12(4), 15-28.
- Chen, X., Chen, Q., Zhang, Z., Cheng, Y., & Qi, Z. (2018). BIM+ Robot creates a new era of building construction. *Journal of Physics: Conference Series, 1069*, 012142.
- Chepachenko, N. V., Leontiev, A. A., Uraev, G. A., & Polovnikova, N. A. (2020). Features of the factor models for the corporate cost management purposes in construction. *IOP Conference Series: Materials Science and Engineering*, *913*, 042075

- Kankhva, V., Andryunina, Y., Belyaeva, S., & Sonin, Y. (2021). Construction in the digital economy: Prospects and areas of transformation. *E3S Web of Conferences, 244*, 05008.
- Čuš Babič, N., & Rebolj, D. (2016). Culture change in construction industry: From 2D toward BIM-based construction. *Journal of Information Technology in Construction*, 21, 86-99.
- Su, Y., Hsieh, Y., Lee, M., Li, C., & Lin, Y. (2013). Developing BIM-based shop drawing automated system integrated with 2D barcode in construction. *Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13)*, Sapporo, Japan.
- Kashlev, D. (2008). Efficient 3D building model generation from 2D floor plans. *Massachusetts Institute of Technology*.
- Liu, Z., Ding, R., Gong, Z., & Ejohwomu, O. F. (2023). Fostering digitalization of construction projects through integration: A conceptual project governance model. *Buildings, 13*(3), 825.
- Zou, J. (2019). Construction and application analysis of construction project cost management information system based on value perspective. *Proceedings of the 2019 5th International Conference on Education, Management, and Information Technology (ICEMIT 2019)*.
- Juninawan, Y. R. Alkhaly, & R. Mirsa. (2023). Implementation of building component drawing automation to enhance time efficiency and accuracy in the construction planning process. *International Journal of Engineering Business and Social Science, 1*(6), 641-653.
- Seyman-Güray, T., & Kısmet, B. (2022). Integrating 4D & 5D modelling into construction management education in architecture: A digitalization framework. *ArtGRID, 4*(2), 172-189.
- Kushwaha, V. (2016). Contribution of Building Information Modeling (BIM) to solve problems in the Architecture, Engineering, and Construction (AEC) industry and

addressing barriers to implementation of BIM. *International Research Journal of Engineering and Technology (IRJET), 3*(1), 100-105.

- Koscheyev, V., & Hakimov, A. (2019). Russian practice of using digital technologies in public procurement management in the construction industry. *IOP Conference Series: Materials Science and Engineering, 497*, 012009.
- Ashworth, A., & Perera, S. (2010). Cost Studies of Buildings (5th ed.). Harlow: Prentice Hall.
- Construction Economics. (2012). Construction Updates. Retrieved from https://constructionduniya.blogspot.com/2012/01/construction-economics_31.html
- Hillebrandt, P. (1985). Economic Theory and the Construction Industry (2nd ed.). London: Macmillan.
- Igwe, U. S., et al. (2020). IOP Conference Series: Materials Science and Engineering, 884, 012041.
- Marsh, Guy Carpenter. (2021). Future of Construction. Retrieved from https://www.marsh.com/ng/industries/construction/insights/global-construction-outlook.html
- McKinsey. (2020). The Next Normal in Construction. US: McKinsey.
- Miller, L. D. (1987). The Strategic Management of Large Engineering Projects: Shaping Institutions, Risks, and Governance. Massachusetts: Massachusetts Institute of Technology.
- Morris, H. G. (1987). The Anatomy of Major Projects: A Study of the Reality of Project Management. Chichester, England: John Wiley & Sons, Inc.
- Myers, D. (2019). Construction Economics: A New Approach (4th ed.). New York: Routledge.
- Ofori, G. (1990). The Construction Industry: Aspects of Its Economics and Management. Singapore: Singapore University.
- Oxford Economics. (2021). Future of Construction. Retrieved from https://www.oxfordeconomics.com/resource/future-of-construction/

- Press Trust of India. (2022). Cost overruns of Rs 4.83 trillion impact 425 infrastructure projects. Retrieved from https://www.business-standard.com/article/current-affairs/cost-overruns-of-rs-4-83-trillion-impact-425-infrastructure-projects-122052200212_1.html
- Sampson Igwe, U., et al. (2020). Recent Technologies in Construction: A Novel Search for Total Cost Management of Construction Projects.
- Lu, W., Lai, C. C., & Tse, T. (2019). BIM and Big Data for Construction Cost Management. London: Routledge.
- Koscheyev, V., Rapgof, V., & Vinogradova, V. (2019). Digital transformation of construction organizations. *IOP Conference Series: Materials Science and Engineering*, *497*(1), 012010.
- Lee, H. W., Oh, H., Kim, Y., & Choi, K. (2015). Quantitative analysis of warnings in building information modeling (BIM). *Automation in Construction, 51*, 23-31.
- Li, Y. (2018). Research on construction projects cost management. *IOP Conference Series: Materials Science and Engineering, 394*, 032057.
- Salem, T., & Dragomir, M. (2022). Options for and challenges of employing digital twins in construction management. *Applied Sciences, 12*(6), 2928.
- Puolitaival, T., & Kähkönen, K. (2022). The modern way of performing construction management responsibilities. *IOP Conference Series: Earth and Environmental Science, 1101*, 042019.
- Byun, Y., & Sohn, B.-S. (2020). ABGS: A system for the automatic generation of Building Information Models from two-dimensional CAD drawings. *Sustainability, 12*(17), 6713.
- Zulu, S. L., Saad, A. M., & Omotayo, T. (2023). The mediators of the relationship between digitalisation and construction productivity: A systematic literature review. *Buildings*, *13*(839).
- Kagan, P. (2021). The use of digital technologies in building organizational and technological design. *E3S Web of Conferences, 263*, 04040.

- Tyurin, I. A. (2020). Automation identification of construction work and structural elements in BIM development. *IOP Conference Series: Materials Science and Engineering, 913*(1), 042010.
- Çıdık, M. S., & Boyd, D. (2022). Value implication of digital transformation: The impact of the commodification of information. *Construction Management and Economics, 40*(11-12), 903-917.
- Vitásek, S., & Matějka, P. (2017). Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic. *IOP Conference Series: Materials Science and Engineering, 236,* 012110.
- Nawari, O. (2012). BIM Standard in Off-Site Construction. *Journal of Architectural Engineering, 18*(2), 107–113.
- Smith, P. (2014). BIM implementation – global strategies. *Procedia Engineering, 85,* 482–492.
- Begić, H., & Galić, M. (2021). A systematic review of Construction 4.0 in the context of the BIM 4.0 premise. *Buildings, 11*(337)
- Chen, L., & Luo, H. (2014). A BIM-based construction quality management model and its applications. *Automation in Construction, 46*, 64–73.

APPENDIX – A

SURVEY COVER LETTER

Questionnaire : Construction Economics : Digitalization in Construction Cost Management

Dear All,

I am conducting a research as part of my doctorate programme in "**Construction Economics**", focusing on the topic of **Digitalization in Construction Cost Management.**
The objective of this research is to gain insights into the current state of digitalization in construction cost management practices, identify the challenges faced by the construction industry in implementing digital tools, and analyse the benefits and advantages of integrating digitalization into cost management procedures.
I kindly request your valuable time to participate in this survey, which is intended solely for academic research purposes.
Note : This survey does not collect any personal identification details, and your responses will be treated with the utmost confidentiality.
Thank you in advance for your time and contribution.

This form is automatically collecting emails from all respondents. Change settings

APPENDIX -B

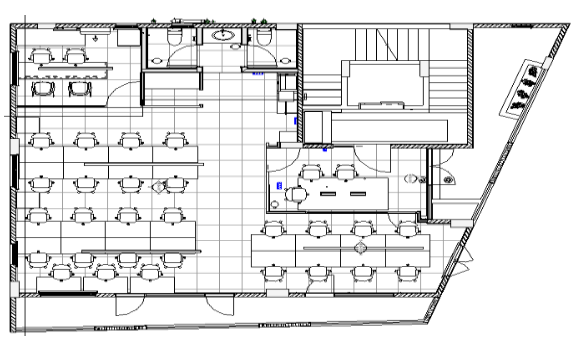
CASE STUDY PROJECTS

PROJECT – 1 : COMMERCIAL – CIVIL INTERIORS

Type : Interior Fit out

Built up area : 6,000 Sft

Veadik project Image - 3D & Actual photo at site



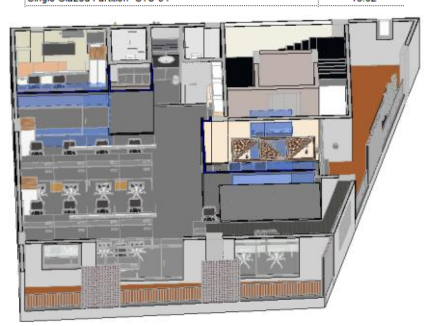
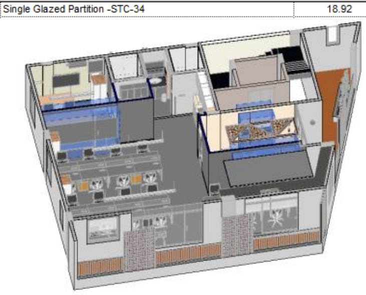
Veadik project Image 1.0 Typical 2D CAD Drawing

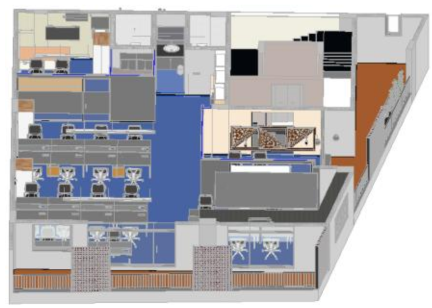
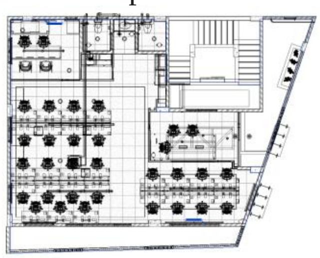
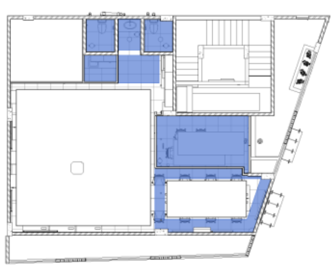
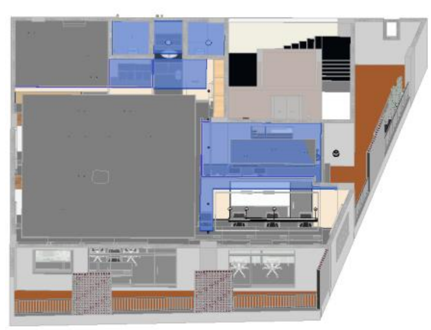
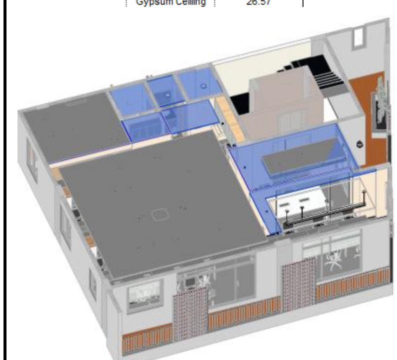
Veadik project Image 1.1 .3D BIM Model

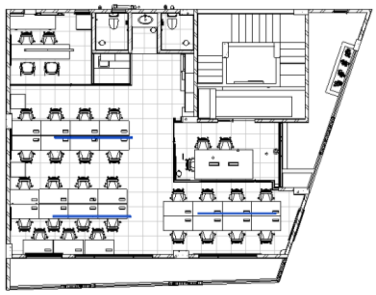
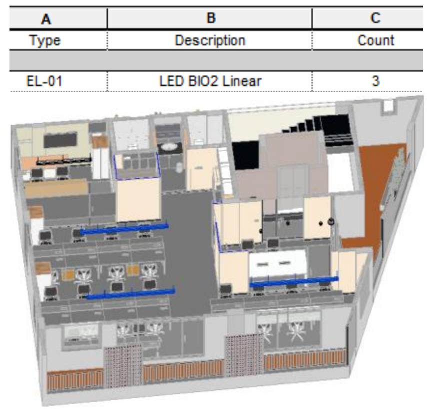
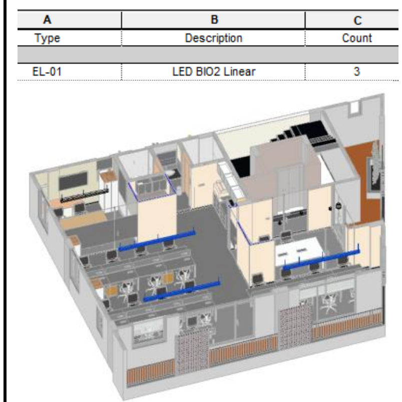
SUMMARY OF QUANTITY TAKE-OFF SUMMARY : indicative

<table>
<tr><th>BIM Model</th><th>Item</th><th>Tender (LOD 350)</th><th>Asbuilt (LOD 500)</th></tr>
<tr>
<td>DP-01</td>
<td>Drywall Partition - 75 mm Thick
</td>
<td>
<WALL SCHEDULE - DP01 Copy 1>
<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><th>ICMS Code</th><th>Type Mark</th><th>Type</th><th>Area (Sqm)</th></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>1.05</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>2.06</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>2.75</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>4.53</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>7.70</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>10.48</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>13.42</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>13.72</td></tr>
<tr><td>rand total: 24</td><td></td><td></td><td>55.70</td></tr>
</table>

</td>
<td>
<WALL SCHEDULE - DP01 Copy 1>
<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><th>ICMS Code</th><th>Type Mark</th><th>Type</th><th>Area (Sqm)</th></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>1.05</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>2.06</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>2.75</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>4.53</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>7.70</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>10.48</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>13.42</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>13.86</td></tr>
<tr><td>04.040.010</td><td>DP-01</td><td>Dry wall Partition 75mm thk</td><td>14.04</td></tr>
<tr><td>rand total: 27</td><td></td><td></td><td>69.88</td></tr>
</table>

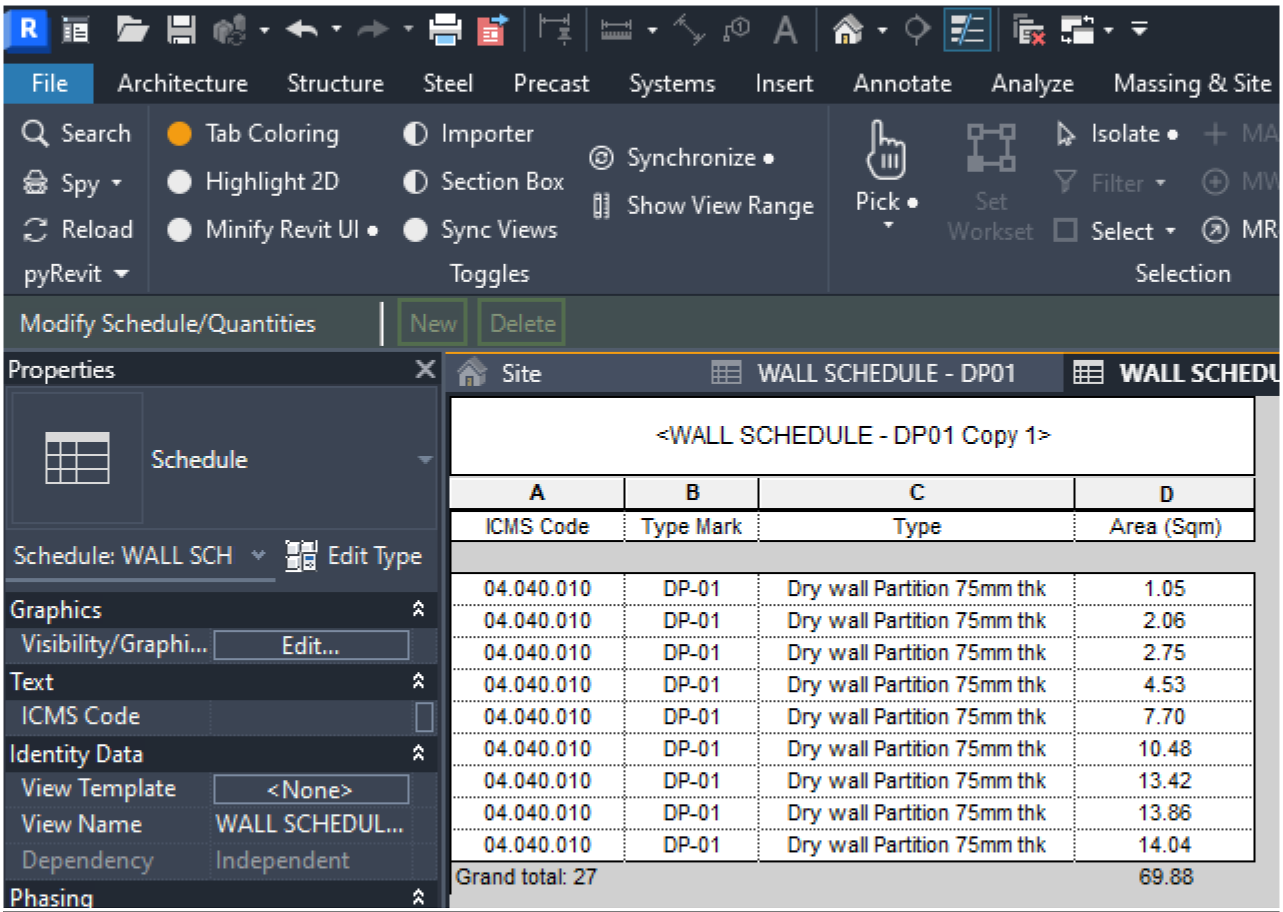
</td>
</tr>
<tr>
<td>SGP-1</td>
<td>Single Glazed Partition - STC-34
</td>
<td>
<table>
<tr><th>A</th><th>B</th></tr>
<tr><th>ICMS Code</th><th>Type Mark</th></tr>
<tr><td>04.040.020</td><td>SGP-01</td></tr>
</table>
<table>
<tr><th>C</th><th>D</th></tr>
<tr><th>Item Description</th><th>Area (Sqm)</th></tr>
<tr><td>Single Glazed Partition -STC-34</td><td>18.92</td></tr>
</table>

</td>
<td>
<table>
<tr><th>A</th><th>B</th></tr>
<tr><th>ICMS Code</th><th>Type Mark</th></tr>
<tr><td>04.040.020</td><td>SGP-01</td></tr>
</table>
<table>
<tr><th>C</th><th>D</th></tr>
<tr><th>Item Description</th><th>Area (Sqm)</th></tr>
<tr><td>Single Glazed Partition -STC-34</td><td>18.92</td></tr>
</table>

</td>
</tr>
</table>

<table>
<tr><th>BIM Model</th><th>Item</th><th>Tender (LOD 350)</th><th>Asbuilt (LOD 500)</th></tr>
<tr><td>VT-01</td><td>Vitrified Tile flooring, 600mm x 600mm
</td><td>A ICMS Code: 04.060.010 · B Type Mark: VT-01 · C Item Description: Vitrified Tile flooring, 600mm x 600mm
D Family: Floor · E Type: Vitrified Floor Tile · F Area: 94.21 m²
</td><td>A ICMS Code: 04.060.010 · B Type Mark: VT-01 · C Item Description: Vitrified Tile flooring, 600mm x 600mm
D Family: Floor · E Type: Vitrified Floor Tile · F Area: 94.21 m²
</td></tr>
<tr><td>SU-01</td><td>DX Split room AC
</td><td>Mechanical Equipment Schedule
ICMS Code · Item Description · BIM Model · QTY · UNIT
05.010.100 · ISU: Generic · SU-01 · 1 · NO
05.010.100 · ISU: Generic · SU-01 · 1 · NO
</td><td>Mechanical Equipment Schedule
ICMS Code · Item Description · BIM Model · QTY · UNIT
05.010.100 · ISU: Generic · SU-01 · 1 · NO
05.010.100 · ISU: Generic · SU-01 · 1 · NO
</td></tr>
<tr><td>GCP01</td><td>Gypsum Ceiling
</td><td>A Code: 0.030 · B Type Mark: GCP01 · C Item Description: Gypsum Ceiling with Paint finish · D Type: Gypsum Ceiling · E Area (Sqm): 26.57
A Code: 0.030 · B Type Mark: GCP01 · C Item Description: Gypsum Ceiling with Paint finish · D Type: Gypsum Ceiling · E Area (Sqm): 26.57
</td><td>A ICMS Code: 04.060.030 · B Type Mark: GCP01 · C Item Description: Gypsum Ceiling with Paint finish
D Type: Gypsum Ceiling · E Area (Sqm): 26.57
</td></tr>
</table>

<table>
<tr><th>BIM Model</th><th>Item</th><th>Tender (LOD 350)</th><th>Asbuilt (LOD 500)</th></tr>
<tr><td>EL-01</td><td>LED Linear Light Fixture
</td><td>
</td><td>
</td></tr>
</table>

Veadik project Image 1.2 Summary of BIM Models

QUANTITY TAKE-OFF DETAILS – REVIT :



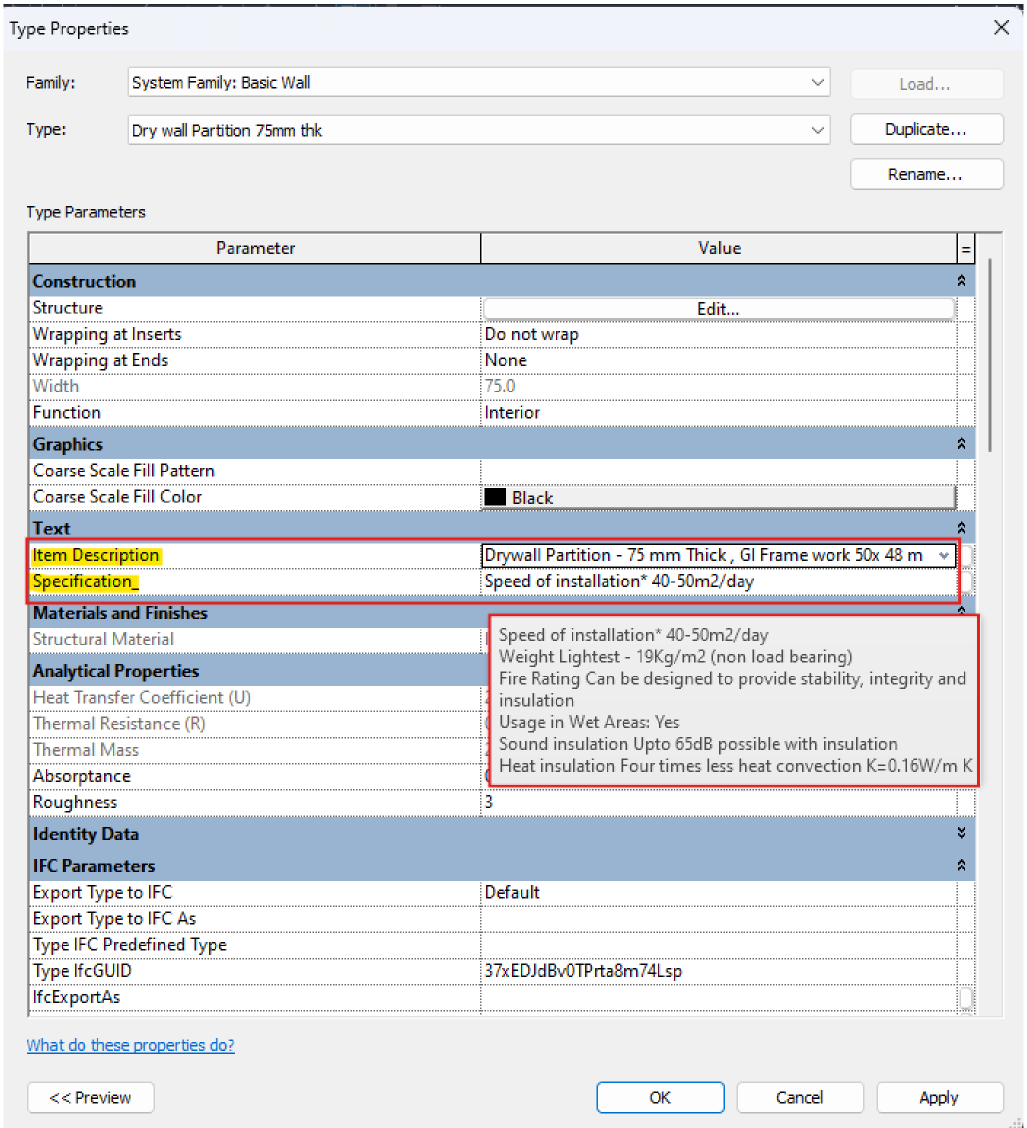
A	B	C	D
ICMS Code	Type Mark	Type	Area (Sqm)
04.040.010	DP-01	Dry wall Partition 75mm thk	1.05
04.040.010	DP-01	Dry wall Partition 75mm thk	2.06
04.040.010	DP-01	Dry wall Partition 75mm thk	2.75
04.040.010	DP-01	Dry wall Partition 75mm thk	4.53
04.040.010	DP-01	Dry wall Partition 75mm thk	7.70
04.040.010	DP-01	Dry wall Partition 75mm thk	10.48
04.040.010	DP-01	Dry wall Partition 75mm thk	13.42
04.040.010	DP-01	Dry wall Partition 75mm thk	13.86
04.040.010	DP-01	Dry wall Partition 75mm thk	14.04
Grand total: 27			69.88

Veadik project Image 1.3 Wall Schedule showing the break-up DP-01

SL.NO.	ICMS CODE	BIM MODEL CODE	DESCRIPTION/SPECIFICATION	UNIT	QUANTITY
1			INTERNAL PARTITIONS		
1.01	04.040.010	ABM-01	Aerated Block Masonry B2 - 150 mm thick.	SQM	17.86
1.02	04.060.020	AP-01	Acrylic Emulsion Paint - 3 Coat	SQM	107.44
1.03	04.060.030	AT-01	Classic Axiom Perimeter Trim	SQM	1.88
1.04	04.060.020	LG-01	Lacquered Glass	SQM	1.61
1.05	04.060.020	LP-01	Laminate Panelling: Providing and fixing of laminate panelling with MDF backing as per the design and architect's approval.	SQM	8.35
1.06	04.060.020	PAP-01	Plain Acoustic Panelling -6mm thk. Supply and installation of 12 mm acoustic Panels for reducing and controlling Reverberated noise	SQM	3.64
1.07	04.060.020	PBP-01	Prelaminate board panelling: Providing and fixing of prelaminate board panelling as per the design and architect's approval.	SQM	11.98
1.08	04.040.020	SGP-01	Single Glazed Partition -STC-34	SQM	18.92
1.09	04.060.020	TLP-01	Texture laminate Paneling: Providing and fixing of grooved MDF panelling with mdf backing as per the design and architect's approval.	SQM	3.62
1.1	04.060.010	VTS-01	Providing and fixing of vitrified tile skirting as per the manufacturer's specification and fixing details. Skirting to match the color of the flooring.	SQM	5.61
1.11	04.030.010	WP-01	Waterproof plaster on Floor and wall	SQM	17.97
1.12	04.060.020	WTC-01	Tile Cladding	SQM	29.65
1.13	04.040.010	DP-01	Dry wall Partition 75mm thk	SQM	69.9
1.14	04.040.010	DP-02	Dry wall Partition 100mm thk	SQM	7.35

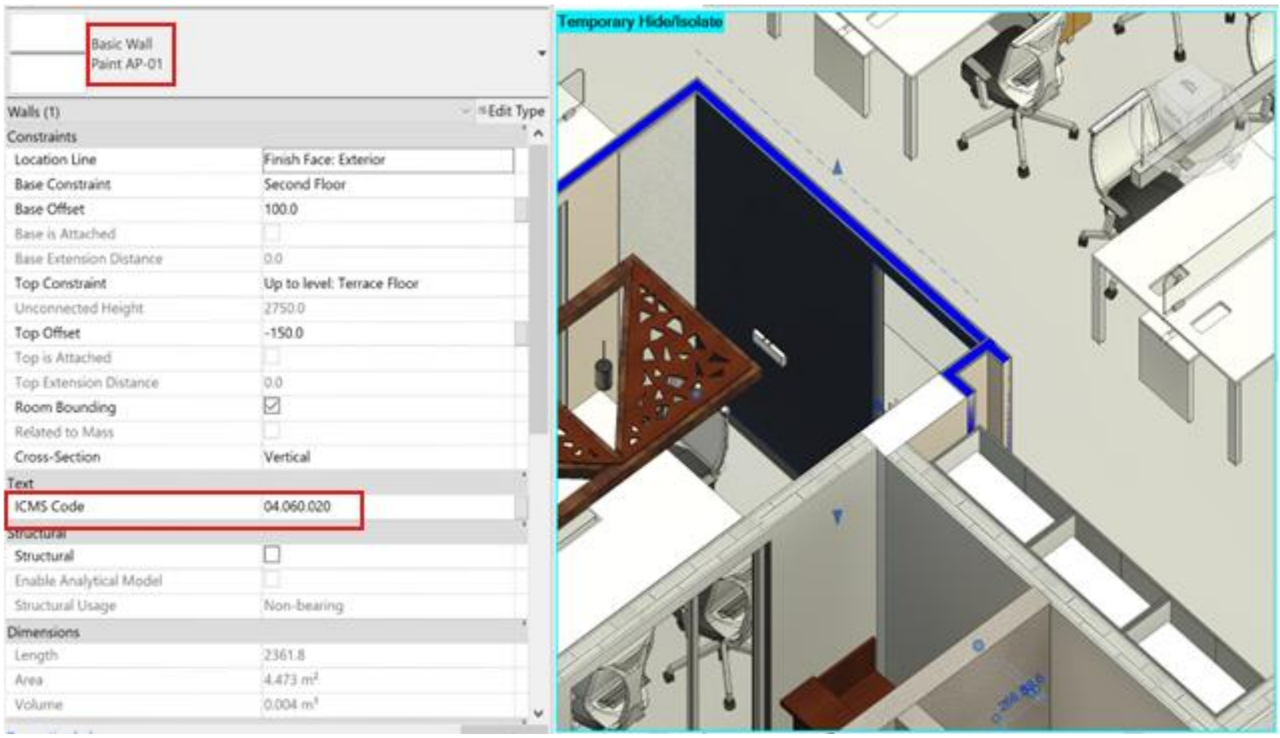
Veadik project Image 1.4 BOQ showing quantities of wall masonry

SPECIFICATION DETAILS – REVIT :



Veadik project Image 1.5 Properties bar showing Description & Specification of a Wall from Revit

IDENTIFICATION OF CODES :



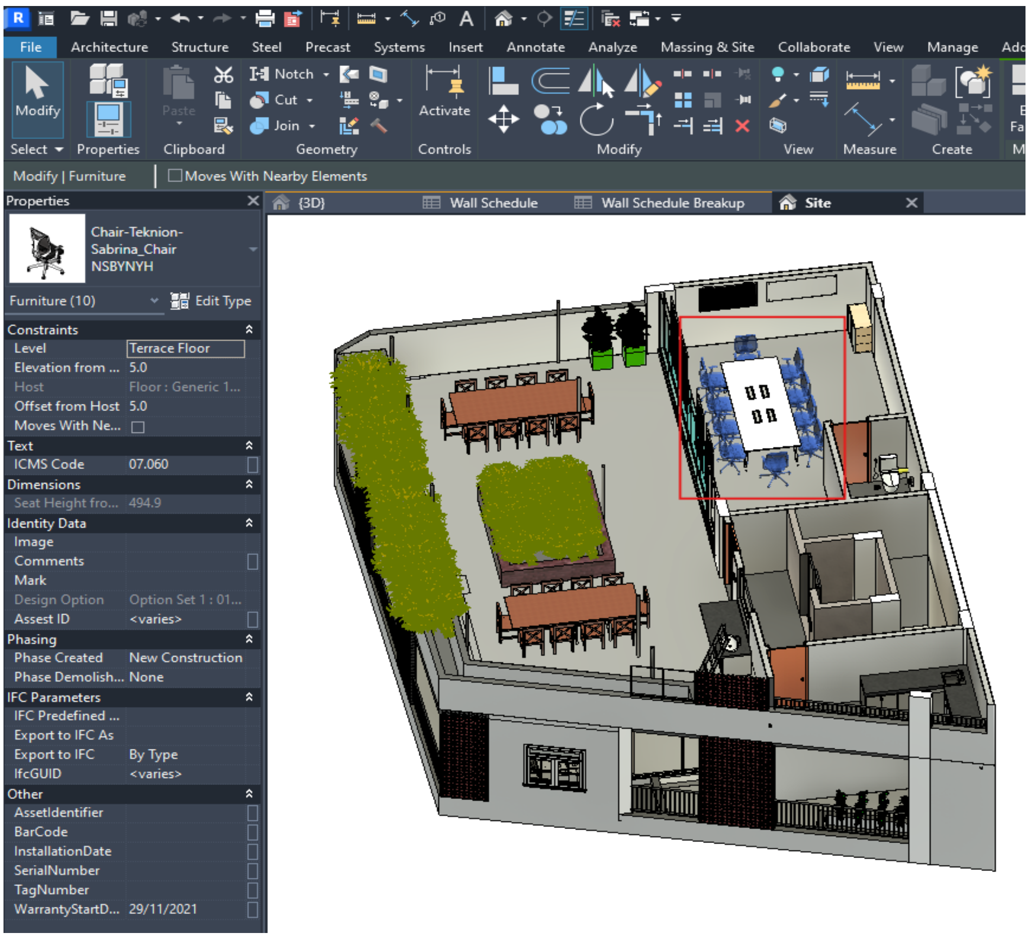
Veadik project Image 1.6 3D model with BIM CODE

SL.NO.	ICMS CODE	BIM MODEL CODE	DESCRIPTION/SPECIFICATION	UNIT	QUANTITY
1			INTERNAL PARTITIONS		
1.01	04.040.010	ABM-01	Aerated Block Masonry B2 - 150 mm thick.	SQM	17.86
1.02	04.060.020	AP-01	Acrylic Emulsion Paint - 3 Coat	SQM	107.44
1.03	04.060.030	AT-01	Classic Axiom Perimeter Trim	SQM	1.88
1.04	04.060.020	LG-01	Lacquered Glass	SQM	1.61
1.05	04.060.020	LP-01	Laminate Panelling: Providing and fixing of laminate panelling with MDF backing as per the design and architect's approval.	SQM	8.35
1.06	04.060.020	PAP-01	Plain Acoustic Panelling -6mm thk.Supply and installation of 12 mm acoustic Panels for reducing and controlling Reverberated noise	SQM	3.64
1.07	04.060.020	PBP-01	Prelaminate board panelling: Providing and fixing of prelaminate board panelling as per the design and architect's approval.	SQM	11.98
1.08	04.040.020	SGP-01	Single Glazed Partition -STC-34	SQM	18.92
1.09	04.060.020	TLP-01	Texture laminate Paneling: Providing and fixing of grooved MDF panelling with mdf backing as per the design and architect's approval.	SQM	3.62
1.1	04.060.010	VTS-01	Providing and fixing of vitrified tile skirting as per the manufacturer's specification and fixing details. Skirting to match the color of the flooring.	SQM	5.61
1.11	04.030.010	WP-01	Waterproof plaster on Floor and wall	SQM	17.97
1.12	04.060.020	WTC-01	Tile Cladding	SQM	29.65
1.13	04.040.010	DP-01	Dry wall Partition 75mm thk	SQM	69.9
1.14	04.040.010	DP-02	Dry wall Partition 100mm thk	SQM	7.35

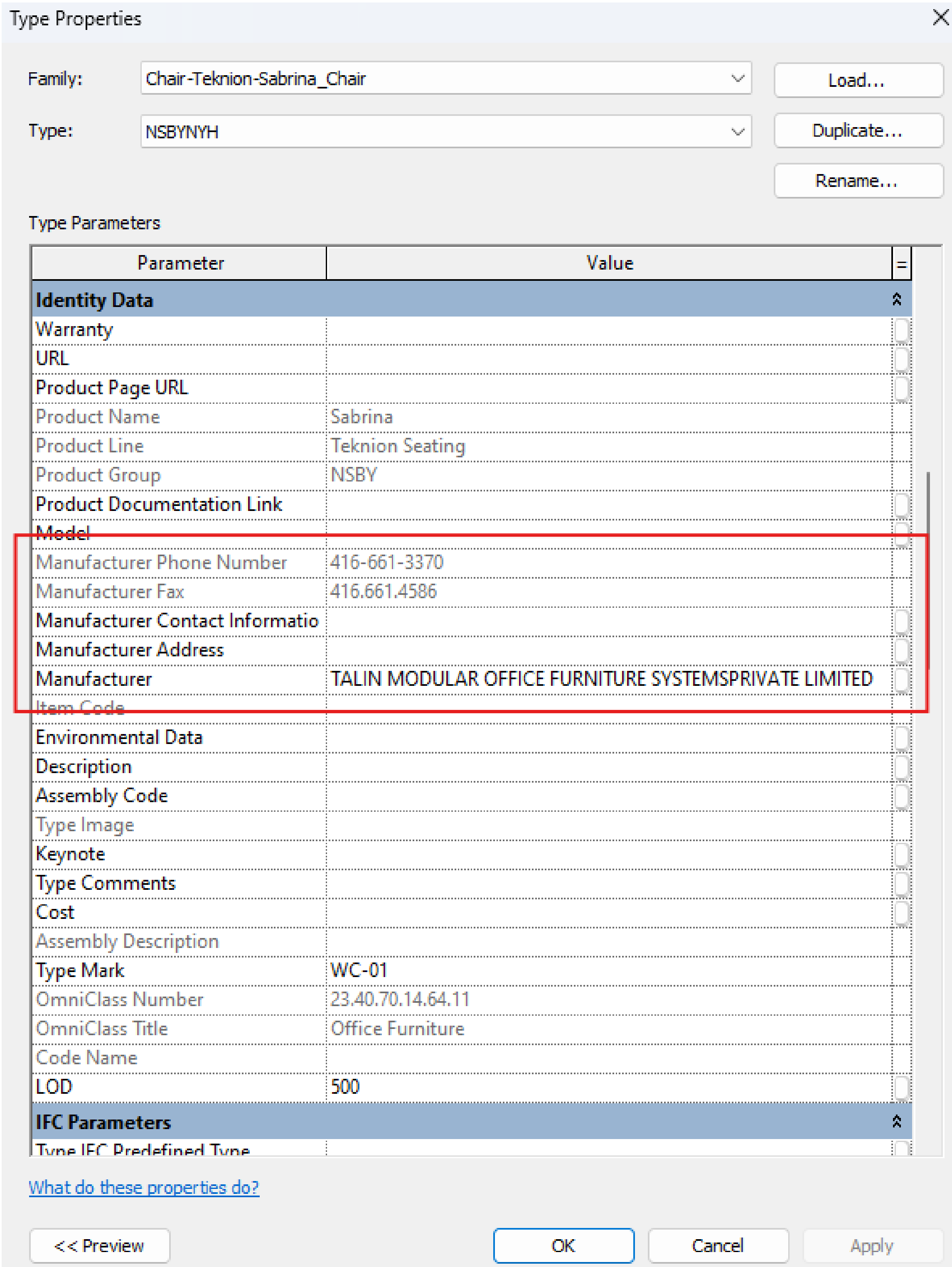
Veadik project Image 1.7 BOQ with BIM code

ASSET LIST (MANUFACTURER) :

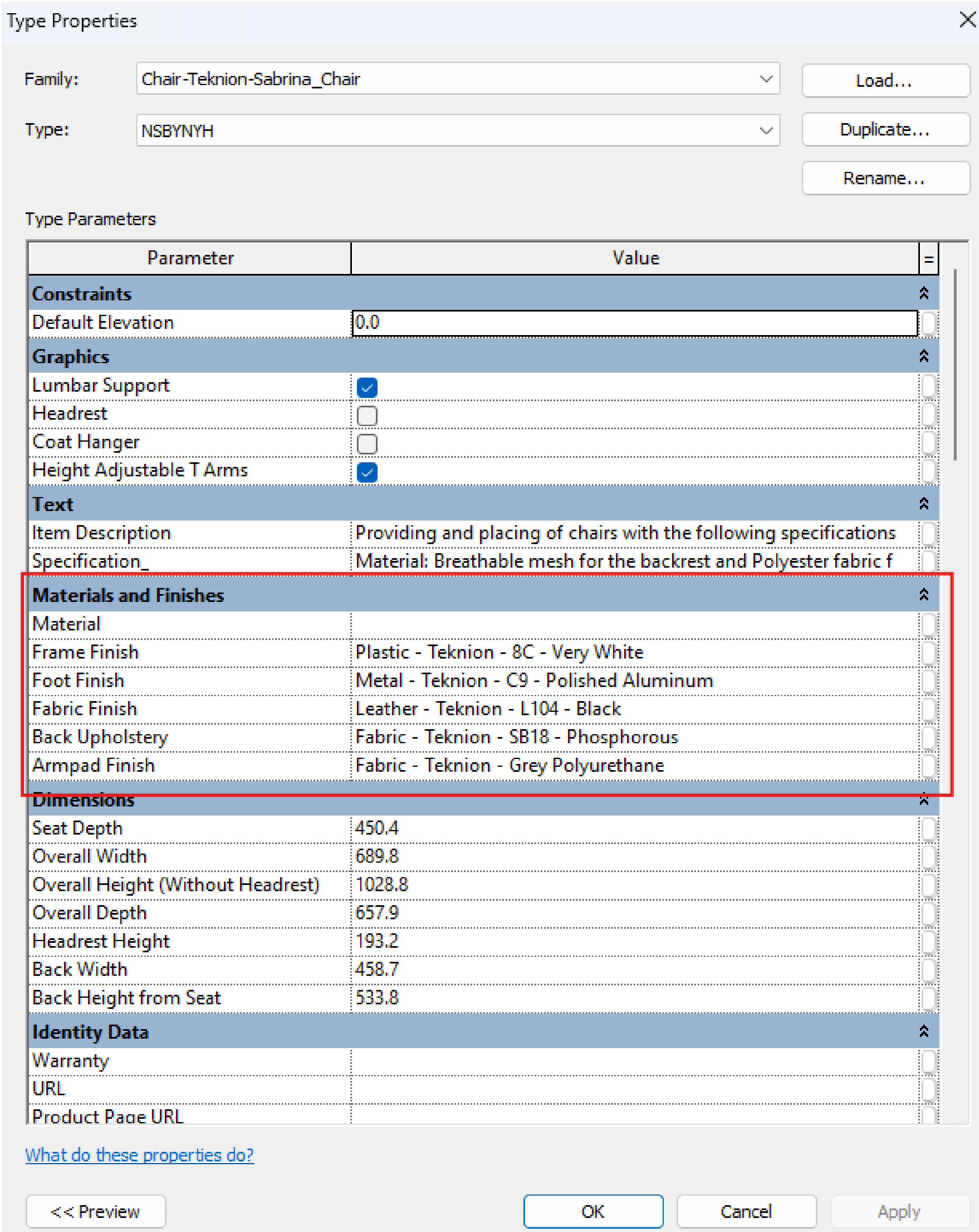
The figure below displays details of assets and their manufacturers for the benefit of operation and maintenance:



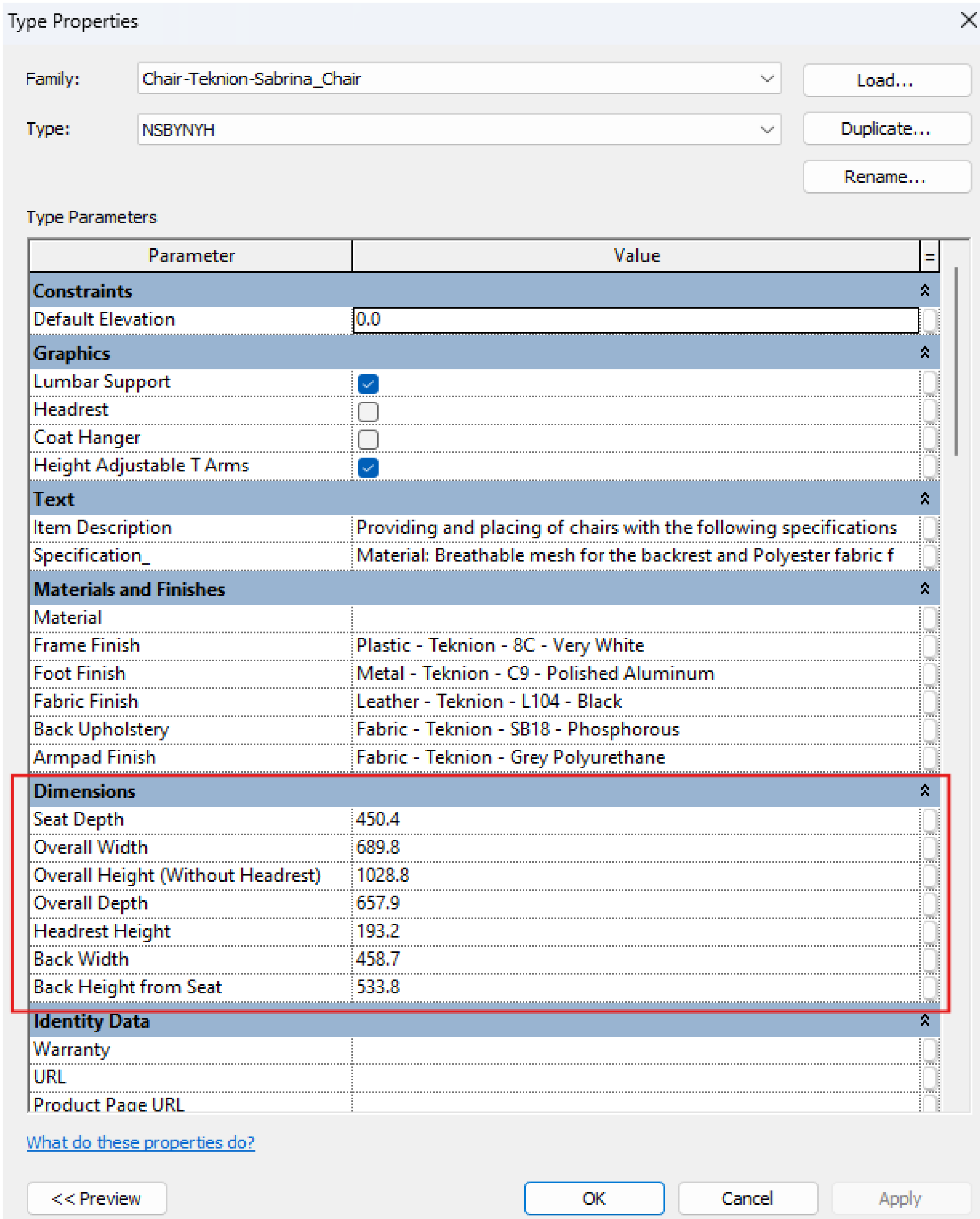
Veadik project Image 1.7 Chair Properties



Veadik project Image 1.8 Manufacturer details



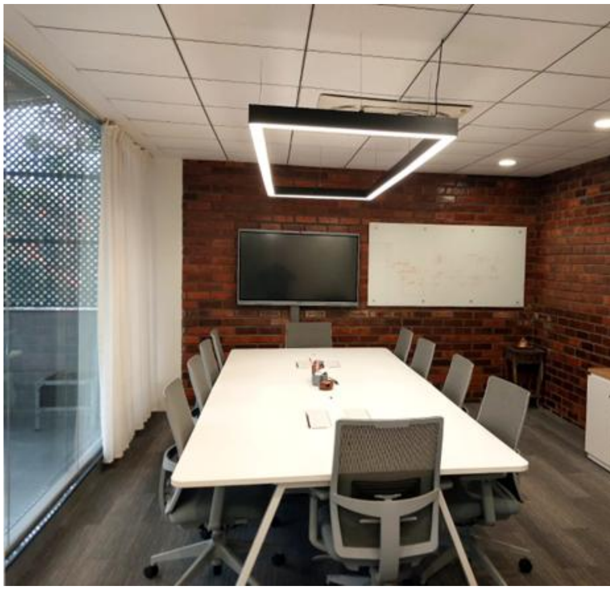
Veadik project Image 1.9 Material details



Veadik project Image 1.8 Chair specification in. BIM

As built and actual photograph at site

Below 3D Model reflects the actual as-built conditions of the project:



Veadik project Image 1.9 . Project photo actual Veadkk project Image 1.10 LOD 500 As-built

Veadik project Image 1.11. Project photo actual Veadik project Image 1.1 LOD 500 As-built