ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

APPLICATION OF 4D/5D BIM IN CONSTRUCTION PROJECT MANAGEMENT: THE CASE OF SELECTED BUILDING PROJECTS IN ADDIS ABABA.

By

EYERUSALEM MELESE MEKONNEN

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University-Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for Master of Civil Engineering Degree in Construction Technology and Management

ADVISOR: ABRAHAM ASSEFA TSEHAYE (PhD)

May 2025

Addis Ababa, Ethiopia

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May 2025

Addis Ababa, Ethiopia

Declaration

I hereby declare that the research titled "Application Of 4D/5D BIM in Construction Project Management: The Case of Selected Building Projects in Addis Ababa." is my own original work and has not been submitted for any degree at any University or any other institution.

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Name of Students **Signatures** **Date**

Endorsement

In my capacity as the research advisor, I hereby attest that I have read and assessed the thesis paper, " Application Of 4d/5d BIM in Construction Project Management: The Case of Selected Building Projects in Addis Ababa." which was written under my supervision by Eyerusalem Melese Mekonnen. I recommend accepting it as a partial fulfillment of the prerequisites for the Master of Civil Engineering degree in Construction Technology and Management.

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Approval Sheet

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Acknowledgement

With the deepest gratitude and high esteem, I wish to express my heartfelt thanks to all those who contributed decisively to the completion of this thesis.

First and foremost, I give all glory and honor to Almighty God, who has been my guide, strength, and source of inspiration throughout this journey. His grace and blessings have made this accomplishment possible.

It is my duty and honor to extend my profound gratitude to my advisor, Abraham Assefa Tsehaye (PhD), for his remarkable dedication, invaluable guidance, and unwavering support throughout my research effort. His expertise, encouragement, and constructive feedback have been instrumental in shaping this work and ensuring its successful completion.

I would also like to express my sincere appreciation to Bexel Manager Consulting for generously providing me with a free one-year educational license trial of their software. This invaluable resource greatly enhanced my ability to explore and apply advanced BIM tools in my research.

My heartfelt thanks go to Ato Fitsum Yonas, for his invaluable insights, support, and collaboration during the study. His practical expertise and willingness to share knowledge were crucial in enriching the quality of this research.

I am also deeply grateful to Ato Zewdu Tefera and all the postgraduate lecturers for their unwavering support and guidance throughout my academic journey. Their contributions have been vital to my development and success.

I am deeply grateful to my family, whose unwavering love, prayers, and encouragement have been my anchor throughout this journey. Their moral and emotional support provided me with the strength to persevere and achieve this milestone.

Finally, I extend my thanks to all individuals and organizations who, in one way or another, contributed to the successful completion of this thesis. Your support and contributions are deeply appreciated.

Thank you all for being part of this journey.

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Acronyms

4D BIM: Four-Dimensional Building Information Modeling (Time)

5D BIM: Five-Dimensional Building Information Modeling (Cost)

AIR: Asset Information Requirement

BCF: BIM Collaboration Format

BEP: BIM Execution Plan

BIM: Building Information Modeling

BIP: BIM Implementation Plan

CDE: Common Data Environment

EIR: Employers Information Requirements

EIR: Exchange Information Requirement

GDP: Gross Domestic Product

ISO: International Organization for Standardization

LOD: Level of Development

LOI: Level of Information

MIDP: Master Information Delivery Plan

OIR: Organizational Information Requirement

PIR: Project Information Requirement

QTO: Quantity Takeoff

SME: Small and Medium-sized Enterprises

TIDP: Task Information Delivery Plan

Abstract

This thesis investigates the application of 4D and 5D Building Information Modeling (BIM) in construction project management, focusing on selected building projects in Addis Ababa. It addresses challenges faced by the Ethiopian construction industry, including low productivity, inadequate schedule control, and ineffective cost management due to traditional project management methods.

The study begins with a comprehensive literature review outlining the theoretical framework of construction project management and the limitations of conventional practices. It emphasizes how technological advancements, particularly BIM, can significantly enhance project outcomes through improved visualization, coordination, scheduling, and cost estimation. A developed 4D/5D BIM framework is applied to three projects: the New Ethiopian National Theatre (Project A), Addis Capital Goods Mixed-Use Building (Project B), and Ethiopian Petroleum Station Mixed-Use Building (Project C). The research highlights how the framework integrates 3D modeling with time (4D) and cost (5D) dimensions to boost project efficiency, accuracy, and transparency.

Key BIM objectives identified include improving design quality, transitioning from conventional designs to integrated BIM workflows, ensuring quality control, and facilitating effective stakeholder communication. By utilizing advanced BIM tools like BEXEL Manager, the study demonstrates the benefits of automated processes such as clash detection, quantity takeoff, cost estimation, and progress monitoring. For Project A, the implementation of a federated BIM model resulted in significant advancements in collaboration, data management, and construction planning.

However, challenges were noted in Projects B and C, including incomplete mechanical systems, undefined model elements, and inconsistencies in work planes. These issues were attributed to deviations from ISO 19650 standards, Ethiopian Standard ES and the lack of critical documents like the BIM Execution Plan (BEP) and Employer's Information Requirements (EIR). The findings indicate that while the projects reached basic BIM maturity (Level 2), substantial gaps remain in achieving higher levels of integration and optimization. Limitations include a shortage of skilled personnel, incomplete data for 4D/5D processes, and reliance on generic models.

To address these gaps, the study emphasizes the need for adherence to ISO 19650 standards, the development of robust BEP and EIR documents, and targeted training programs for stakeholders. The research concludes with a roadmap for improving BIM maturity, transitioning from basic 3D modeling to fully integrated 4D/5D workflows. By addressing identified gaps, the Ethiopian construction industry can fully realize BIM's potential, thereby setting a benchmark for large-scale public infrastructure projects. This study contributes to the knowledge on BIM implementation, offering practical insights and recommendations for advancing BIM adoption in resource-constrained environments.

Key Words; *Building Information Modeling (BIM), 4D BIM, 5D BIM, Construction Project Management, Project Visualization, Schedule Management, Cost Management,*

1 INTRODUCTION

1.1 Background of the study

The construction industry is a cornerstone of global economic development, delivering the infrastructure essential for societal advancement and economic activity. This sector encompasses a broad spectrum of activities, including residential, commercial, industrial, and infrastructure projects. Its contribution to the economy is substantial, driving job creation, GDP growth, and the development of critical facilities and services (World Bank, 2020; Ofori, 2015).

Globally, the construction sector is one of the largest and most influential industries, generating annual revenues of approximately $10 trillion, with projections suggesting an expansion to nearly $15 trillion by 2030 (Global Construction Perspectives & Oxford Economics, 2015; World Economic Forum, 2016). Despite its size and significance, the industry remains complex and highly fragmented, involving diverse stakeholders such as developers, contractors, architects, engineers, and suppliers. As such, effective project management is essential to deliver projects on time, within budget, and to the required quality standards. However, traditional project management practices frequently encounter challenges such as delays, cost overruns, and coordination failures among project participants (Flyvbjerg et al., 2003; Memon et al., 2012; Doloi et al., 2012).

In recent years, technological advancements have begun transforming how construction projects are planned, designed, and managed. Tools such as Building Information Modeling (BIM), virtual reality (VR), drones, and advanced project management software have revolutionized industry practices (Volk et al., 2014; Alaloul et al., 2020). Among these, BIM stands out for its integrated and multidimensional approach to project management, combining spatial (3D), time (4D), and cost (5D) data into a unified digital model (Eastman et al., 2011; Azhar, 2011).

The adoption of BIM has shown considerable benefits, including improved visualization, enhanced stakeholder coordination, reduction in rework, and more effective time and cost control. According to a report by McGraw Hill Construction (2020), over 75% of BIM users experienced positive returns on investment, with notable improvements in project outcomes (Ribeirinho et al., 2020; Wong & Fan, 2013). BIM supports informed decision-making by providing accurate, real-time information throughout the entire project lifecycle (Azhar et al., 2011; Succar, 2009).

In the context of developing countries, the construction industry is critical to national development, particularly in providing housing and essential infrastructure. However, these nations often face distinctive challenges, such as limited financial capacity, inadequate infrastructure, and shortages of skilled labor (Ofori, 2015; Thomas et al., 2002). Despite these hurdles, there is increasing recognition of the value of digital tools like BIM in improving efficiency, productivity, and overall project performance (Abdirad, 2017; Ghaffarianhoseini et al., 2017).

Ethiopia's construction industry is a pivotal sector in its economic development strategy. The sector has experienced rapid growth, fueled by increased investments in infrastructure, housing, and commercial developments. According to the World Bank (2022), Ethiopia's construction sector GDP averaged 299.27 ETB billion between 2012 and 2021, reaching a peak of 468.44 ETB billion in 2021. Nonetheless, the industry is loaded by common challenges, including project delays, budget overruns, and inadequate coordination among stakeholders (Mengistu, 2019; Belay et al., 2021). Traditional project management methods often fail to effectively address these issues, leading to inefficiencies and suboptimal outcomes (Porwal & Hewage, 2013).

The implementation of 4D (time) and 5D (cost) BIM presents a promising solution to these challenges by enhancing project planning, scheduling, and cost control (Barlish & Sullivan, 2012). However, BIM adoption in Ethiopia remains limited due to barriers such as high initial costs, lack of technical expertise, and resistance to change (Belay et al., 2021; Abdirad, 2016). Nonetheless, evidence from other developing countries indicates that with appropriate support and strategic initiatives, these obstacles can be successfully addressed (Cao et al., 2015; Wong et al., 2011).

The selected building projects in Addis Ababa provide relevant case studies for examining the practical application of 4D/5D BIM in the Ethiopian construction context. These projects, which encounter many of the typical challenges faced across the sector, offer a valuable opportunity to explore how advanced digital tools can improve project management practices, strengthen coordination among stakeholders, and achieve better control over time and cost.

1.2 Statement of the problem:

The construction industry in Ethiopia, as in many developing countries, plays a critical role in national economic development through the delivery of vital infrastructure, housing, and commercial facilities. However, the sector continues to face persistent challenges in project management, particularly in terms of cost overruns, schedule delays, substandard quality, and low productivity. These challenges not only undermine project success but also hinder economic growth, reduce stakeholder trust, and affect urban development efforts.

Traditional project management approaches — such as Gantt charts, Critical Path Method (CPM), and manual reporting — have served as foundational tools in the industry for decades. They have contributed significantly to organizing work processes and guiding construction delivery. However, as project complexity increases and demands for integration, accuracy, and real-time responsiveness grow, these conventional methods often fall short in addressing modern construction needs. They tend to lack the dynamic capabilities needed for efficient coordination, integrated data handling, and visual simulation, particularly in large or fast-paced projects (Porwal & Hewage, 2013; Succar, 2009).

In the Ethiopian context, these limitations are more pronounced due to factors such as fragmented communication, inefficient scheduling, and limited access to timely information. Studies have shown that ineffective planning, resource allocation, and weak cost control mechanisms are among the leading causes of delays and budget overruns in Ethiopian construction projects (Ayele, 2022; Koshe & Jha, 2016; Hailemicheal, 2023). Furthermore, the sector continues to struggle with low productivity, driven by a combination of manual workflows, skill shortages, and minimal technological investment (Barbosa et al., 2017; Borrmann et al., 2018).

Figure 1 illustrates how productivity levels in the construction business have not changed over the last 20 years in comparison to other industries. In the construction industry, this condition leads to lower profit margins and more cost uncertainty. The quality of the finished product has suffered as a result of attempts to cut labor costs by using temporary laborers with lower skill levels(Borrmann et al., 2018).

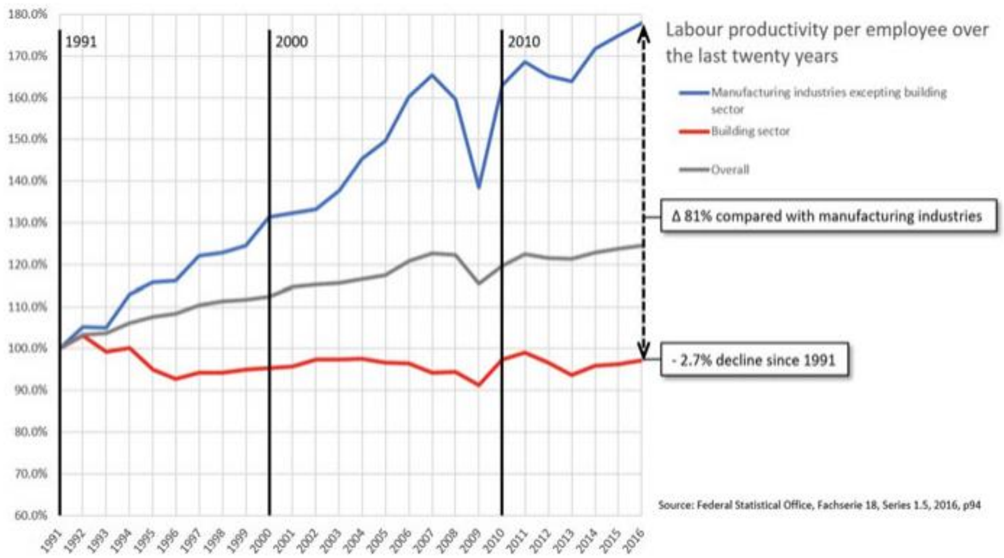


Figure 1 The productivity of the building sector compared with other manufacturing industries (Borrmann et al., BIM Book, 2018)

In response, global practices increasingly emphasize the integration of digital construction tools, particularly Building Information Modeling (BIM), to support improved project delivery. 4D BIM allows for the visualization and simulation of project timelines, while 5D BIM supports accurate and dynamic cost estimation. Together, these tools enhance decision-making, stakeholder coordination, and schedule and budget control (Azhar, 2011; Eastman et al., 2011). Additionally, technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) are beginning to play a role in predictive planning, progress tracking, and resource optimization (Alaloul et al., 2020).

Despite the growing global adoption of these innovations, implementation of 4D/5D BIM in Ethiopia remains limited, largely due to barriers such as high initial investment, lack of skilled personnel, and resistance to change within project environments (Belay et al., 2021). These gaps present a valuable opportunity to explore how enhanced digital practices can complement and build upon traditional methods, rather than replace them, to meet the evolving needs of the industry.

This study, therefore, aims to assess the application of 4D and 5D BIM in selected building projects in Addis Ababa, examining their potential to improve project performance through better coordination, visualization, scheduling, and cost control. The findings are expected to contribute to the broader goal of enhancing construction project management practices in Ethiopia by integrating traditional strengths with modern capabilities.

1.3 Research questions:

1. What are the benefits derived from the implementation of 4D/5D BIM in the selected building projects in Addis Ababa?
2. What are the difficulties and challenges encountered during the implementation of 4D/5D BIM in these projects?
3. What are the key lessons learned and recommendations for successful 4D/5D BIM implementation in these case study projects and for the Ethiopian construction industry?

1.4 Objective of the study

1.4.1 General Objective:

The general objective of this study is to investigate the application of 4D/5D BIM during the construction phase of the selected building projects in Addis Ababa.

1.4.2 Specific Objectives:

1. To identify and analyze the specific benefits of implementing 4D/5D BIM in the selected building projects in Addis Ababa.
2. To examine and assess the difficulties and challenges encountered during the implementation of 4D/5D BIM in the selected building projects in Addis Ababa.
3. To generate key lessons learned and provide recommendations and framework for successful 4D/5D BIM implementation in these projects and for the Ethiopian construction industry.

1.5 Scope of the Study:

The scope of this study is focused on the application of 4D/5D BIM during the construction phase of selected building projects in Addis Ababa. It aims to investigate the specific benefits, challenges, and best practices associated with implementing 4D/5D BIM in this particular case. While the study is centered on the selected building projects in Addis Ababa, the findings and recommendations can have broader implications for the construction industry in Ethiopia.

1.6 Significance of the study

The study can provide practical insights into the benefits and difficulties of implementing 4D/5D BIM in actual construction projects in Ethiopia. By analyzing real-world case studies, the study can shed light on the specific challenges faced by construction practitioners and offer recommendations to overcome these challenges. The findings can help industry professionals make informed decisions regarding the adoption and utilization of 4D/5D BIM, leading to improved project outcomes and increased efficiency in the Ethiopian construction industry.

1.7 Organization of the Thesis

This research is organized into six chapters, each addressing a key aspect of the study. Chapter 1 provides an introduction to the thesis, covering the background of the study, the research problem, objectives, significance, and scope. Chapter 2 is dedicated to a comprehensive review of relevant literature, encompassing both theoretical and empirical studies to establish the study's foundation. Chapter 3 outlines the research design and methodology, detailing the approaches employed and methods used. Chapter 4 presents the proposed framework for 4D/5D BIM implementation, emphasizing its structure and application. Chapter 5 focuses on the implementation of the proposed framework, providing an in-depth analysis of findings, discussions, and insights gained from the case study. Finally, Chapter 6 concludes the research by summarizing key findings, offering important recommendations, and suggesting directions for future work, ensuring the study’s contributions are clear and actionable.

2 LITERATURE REVIEW

2.1 Theoretical framework of Construction Project Management

Construction project management, as defined by Walker (2015), is a comprehensive process that includes planning, execution, implementation, coordination, and control of a construction project from start to finish. The primary purpose is to fulfil the client's expectations while making sure that the project is completed on time, within budget, and to the required quality standards (Walker, 2015).

Construction project management (CPM) encompasses the application of knowledge, skills, software, and techniques to effectively manage project activities and meet specific technical and operational requirements(Project Management Institute, 2016; Sears et al., 2008).

Smith (2003) also defines construction project management as a systematic approach that involves directing and coordinating both human and material resources throughout the project's lifecycle. This process employs modern management techniques to achieve specific goals related to scope, cost, time, quality, and participant satisfaction. The definition underscores the significance of planning, organization, monitoring, and control of all project aspects, as well as the motivation of all stakeholders to ensure that project objectives are met safely and within established criteria (Smith, 2003).

Overall, Construction project management is portrayed as a complex field that necessitates a blend of technical skills, management expertise, and interpersonal abilities to successfully navigate challenges associated with construction projects(Sears et al., 2008; Walker, 2015).

As reported in the National Bank of Ethiopia's Annual Report for 2021/2022, the manufacturing sector grew by 4.8 percent as shown in **Figure 2** and represented about 23.4 percent of the total industrial output. Conversely, the construction sector was the most significant contributor, making up 72.2 percent of industrial output, primarily driven by substantial investments in building roads, railways, dams, and residential properties.

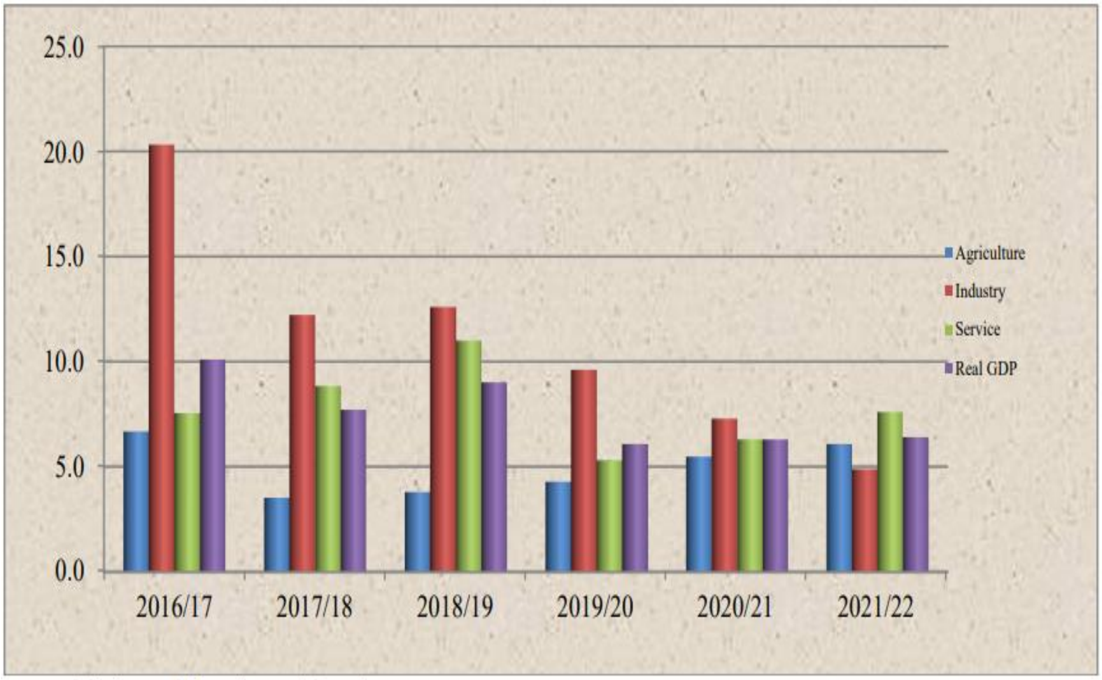


Figure 2 Real GDP growth by the sectors (Source Ministry of Planning and Development as cited on National Bank of Ethiopia Annual Report 2022)

However, the Ethiopian construction industry faces several significant challenges that hinder its performance. Key issues include time management, with average schedule slippage reported between 61-80%, and cost management, where projects frequently experience overruns of 21-40% from planned budgets. Quality management is also a concern, as indicated by low performance scores in maintaining standards. Additionally, the industry struggles with effective risk management, leading to potential project failures, and faces challenges in resource management, particularly in the allocation and utilization of materials, manpower, and equipment collaboration among stakeholders, and capacity building within the sector(Ayalew et al., 2016).

2.1.1 Traditional Construction Project Management

Traditional construction project management (CPM) methods faced challenges due to the linear, document-centric nature of processes prior to digital innovations (Solihin & Eastman, 2015). Planning typically relied on fragmented software like MS Project and spreadsheets that lacked integration with designs and field data (Wu et al., 2014).

Paper-based documentation impaired information accessibility across stakeholders (Hartmann et al., 2012). Scheduling difficulties arose from static Gantt charts lacking feedback mechanisms between programs (Karan & Irizarry, 2015). Site layouts extracted from two-dimensional drawings hampered constructability reviews (Dawood, 2011).

Quality and safety oversight further suffered without centralized databases for real-time data capture and analysis (Sattineni & Bradford, 2011). Manual communications among project teams incurred errors from disjointed storage in physical documents prone to loss or damage. Lack of version control and concurrent collaboration exacerbated coordination issues (Chinyio & Akintoye, 2008).

Risk management also faced challenges reviewing alternatives without integrated 3D spatial contexts. Conflicts arose from improper information handovers across design consultants (Leite et al., 2011). Such fragmentations undermined CPM efficacy, jeopardizing cost, schedule and quality goals in an industry impacted greatly by uncertainty (Olawale & Sun, 2010).

2.2 Construction Project Planning

Construction project planning and scheduling represent crucial aspects of construction process management that directly influence project success. By facilitating resource allocation over time, scheduling helps ensure timely completion within budget(PMBOK® GUIDE, 2017). Additionally, planning enables evaluation of project feasibility, cost estimation, safety, optimization of resource use, as well as monitoring and control of progress to ensure achieving client objectives (Construction Engineering and Management, 2022).

2.2.1 Traditional Construction Planning Methods

Traditional project planning and scheduling methods supported early construction management but faced limitations that new technologies aim to address. Gantt charts proposed by Gantt (1910) facilitated mapping of interdependent activities via horizontal bars alongside a timescale, enabling visualization of plan progress. However, such schedules lacked feedback checks and required manual effort to ensure coordination across stakeholders(Alzraiee et al., 2015)

Network-based techniques including Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) addressed feedback needs by graphically modeling tasks as nodes connected by arrows representing dependencies. While enhancing comprehension of schedule floats and impacts, these methods depended on dispersed data storage in paper documents and spreadsheets prone to errors from manual updates (Alzraiee et al., 2015; Liu et al., 2015).

Bar charts represent basic visualization of milestone and phase durations yet fail to explicitly reveal logical links influencing sequencing. Similarly, Time charts display planned versus actual progress over time but exclude necessary information for coordination (HarithaMahalakshmi et al., 2017; Nouban & Ghaboun, 2017). Such limitations impeded collaboration and conflict resolution among distributed teams.

As projects grew increasingly complex, preconstruction planning transitioned from basic graphs to standalone scheduling software yet still relied substantially on two-dimensional representations. Even integrated programs involving Primavera, Microsoft Project and Asta Power project supported discrete resource and cost management more than model-based constructability reviews essential for improved productivity (Sinesilassie et al., 2017; Sreenivas & Kumar, 2015).

Overall, Traditional scheduling techniques have been shown to lack effective feedback mechanisms, making it difficult to coordinate projects and resolve issues amongst distributed teams.

2.3 Construction Cost Estimation

Construction cost estimation is a crucial process in the construction industry, serving as the foundation for financial planning and management of construction projects(PMBOK® GUIDE, 2017). The accuracy of cost estimations directly influences the economic feasibility and overall success of a project (Sears et al., 2008). Various studies have explored different methods and techniques for construction cost estimation, aiming to improve accuracy and efficiency.

Cost estimates are not static figures but are subject to various influencing factors that can change over time, making the estimation process dynamic and multifaceted. The dynamic nature of construction cost estimation is influenced by factors such as market conditions, project scope changes, resource availability, and unforeseen events(Project Management Institute, 2016; Sears et al., 2008; Smith, 2003). These factors can cause fluctuations in the estimated costs, necessitating continuous monitoring and updating of the cost estimate throughout the project lifecycle. By recognizing the estimate as a reflection of a dynamic system, project managers and cost estimators can better anticipate changes and implement strategies to maintain control over project finances(Alzraiee et al., 2015).

Furthermore, the emergence of machine learning techniques has revolutionized cost prediction, offering software to handle large datasets and improve the accuracy of cost forecasts(Tayefeh Hashemi et al., 2020). These techniques range from statistical models to analogues and analytical models, each with unique features that cater to different aspects of construction cost estimation.

2.3.1 Traditional QTO and Cost Estimating Methods

Traditional QTO methods are primarily manual or 2D-based processes that have been the cornerstone of construction cost estimation for decades. These methods involve estimators reviewing blueprints and additional requirements to calculate the quantities of construction work, which are then used to create pricing and the bill of quantities (BOQ). Despite the coming on of technology, many practitioners still rely on these traditional methods due to their familiarity and historical data availability(Clark, 2019; Zhang & Gao, 2013)

One of the key challenges with traditional QTO is the time-consuming and error-prone nature of the process. Relevant building information must be collected from drawings and unstructured documents, which may be ineffective or inconsistent. This can lead to inaccuracies in cost estimation and inefficiencies in the construction process (Mattern et al., 2018)

Wahab and Wang (2022) conducted a significant comparison between traditional 2D takeoff and BIM-based quantity takeoff and identified 19 factors across four broad categories: timely decision-making, accuracy, collaboration, and level of details. Their research discovered that employing BIM for the QTO process results in increased productivity, accuracy, clarity, and collaboration among team members (Wahab & Wang, 2022).

The study also suggest that while traditional techniques are based on historical data and expert judgment, they often lack the collaboration and communication found in more modern, responsive techniques. This can result in a disjointed flow of information and common changes in design within the early project phases, making manual generation of QTOs a less efficient task(Wahab & Wang, 2022).

In summary, these studies have demonstrated that traditional project management methods face inherent difficulties in key areas such as coordination, information accessibility, change management and progress tracking due to lack of integrated digital workflows and feedback loops between fragmented data formats which pushes the construction industry in to the adoption of BIM, which is not just a technological change but also a process change (Eastman, 2011).

2.4 Building Information Modelling (BIM)

2.4.1 BIM Definition

2.4.1.1 BIM as Building Information Modeling

Building Information Modelling (BIM) is defined by the International Organization for Standardization (ISO) 19650 standard as "*digital representation of physical and functional characteristics of a facility...serving as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle*" (ISO, 2018a).

BIM has also been defined as the use of digital technologies to maintain an accurate virtual model of a building or infrastructure asset throughout its lifecycle, from initial design to fabrication and construction, operation, maintenance, and eventual deconstruction or demolition (Borrmann et al., 2018).

2.4.1.2 BIM as Building Information Model

BIM as Building Information model is the thing that is produced-the content being created as a result of the process which is a shared digital representation of physical and functional characteristics of a built environment asset (NBIMS-US, V3).

BIM models encompass graphical BIM models, non-graphical BIM models and BIM model documents.

Graphical BIM Models

The graphical BIM models refer to the visual representations of a building, including 2D drawings and 3D models, which are essential for understanding the spatial relationships and design intent of a construction project.

According to Eastman et al. (2011), graphical BIM models enhance understanding and communication among project stakeholders, facilitating better decision-making and reducing errors during the design and construction phases. Furthermore, Graphical BIM models improve clash detection and coordination, leading to increased construction efficiency and productivity(Eastman, 2011).

Non-Graphical BIM Models

Non-graphical BIM models encompass the non-visual data and information associated with building elements. These models include attributes such as cost, quantity, material properties, and performance specifications. Non-graphical BIM models provide essential information for cost estimation, procurement, and facility management. They enhance collaboration and information sharing between different project disciplines and stakeholders, improving project outcomes (Arayici et al., 2012).

BIM Model Documents

BIM model documents are the documentation associated with BIM models, including drawings, specifications, and other relevant files. These documents provide comprehensive information about the project, facilitating understanding and coordination among project participants. According to Eastman et al. (20111), BIM model documents serve as a central repository of project information, ensuring consistency, accuracy, and accessibility throughout the project lifecycle (Eastman, 2011).

The combination of graphical, non-graphical data and documents in BIM, managed within a Common Data Environment (CDE), ensures that all project information is stored, accessible, and updatable by all project participants. This holistic approach to information management is critical for the successful delivery of complex construction projects(Montague, 2016).

Figure 3 Graphical Data, Non-graphical Data and BIM Documents representation

Common Data Environment (CDE)

CDE is described as a shared digital project environment with discrete access points for each project stakeholder, as well as well-defined status definitions and a comprehensive workflow description for sharing and approval procedures (Borrmann et al., 2018).

CDE enhances collaboration in construction projects by centralizing project data and information, creating a single source of truth, improving efficiency and quality, reducing risk, and strengthening security. Digital technologies, when used correctly, can improve coordination, teamwork, and decision-making across projects and companies. A CDE also reduces input errors and lost information, enabling faster decision-making and continuous improvement (*ISO 19650, the Common Data Environment, and Autodesk Construction Cloud | Autodesk University*, 2024).

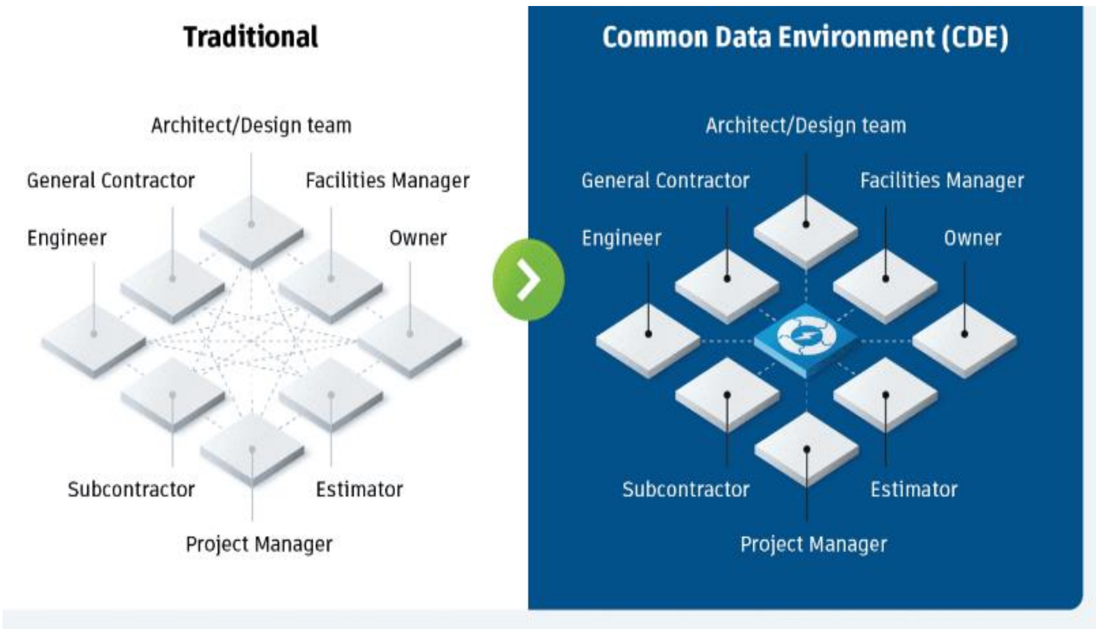


Figure 4 Information sharing in construction, Traditional information flow versus common data environment (ISO 19650, the Common Data Environment, and Autodesk Construction Cloud | Autodesk University, 2024.)

Workflows in Common Data Environment (CDE)

The CDE workflow results in information models with federated information deliverables that take into account the opinions of all stakeholders involved. The information management process should take into account local practices, requirements for interested parties and appointing parties, and any agreements or specifications unique to project delivery or asset management (ISO 19650-1:2018(E)).

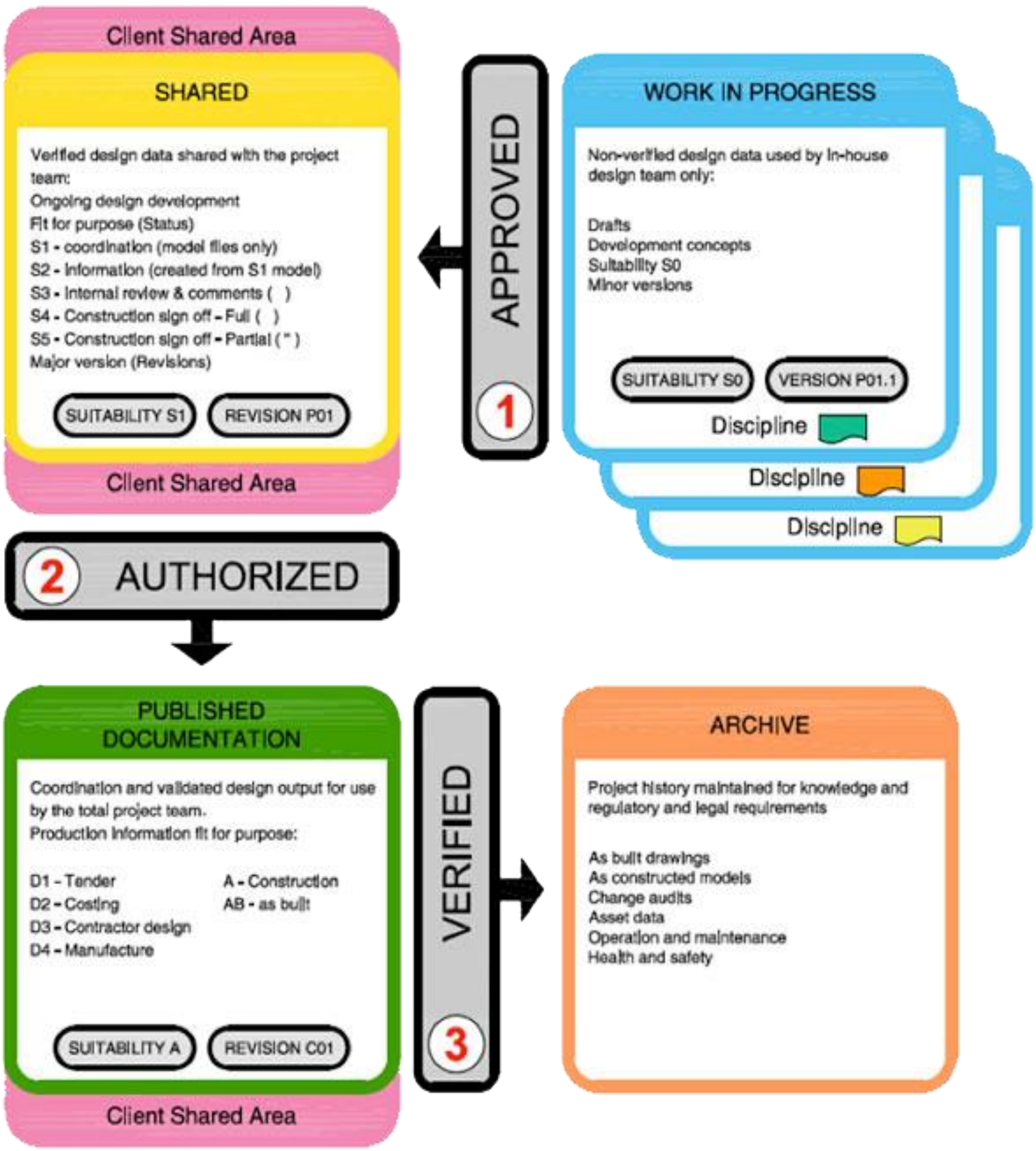


Figure 5 Common Data Environment (CDE) Workflow (ISO 19650-1:2018(E)).

2.4.1.3 BIM as Building Information Management

BIM as Building Information Management emphasizes that who, what and when produces the thing the control and management aspects of the process to ensure production of the information. “It is the function of controlling the acquisition, analysis, retention, and distribution of built environment asset information all within an information processing system (” NBIMS-US, V4).

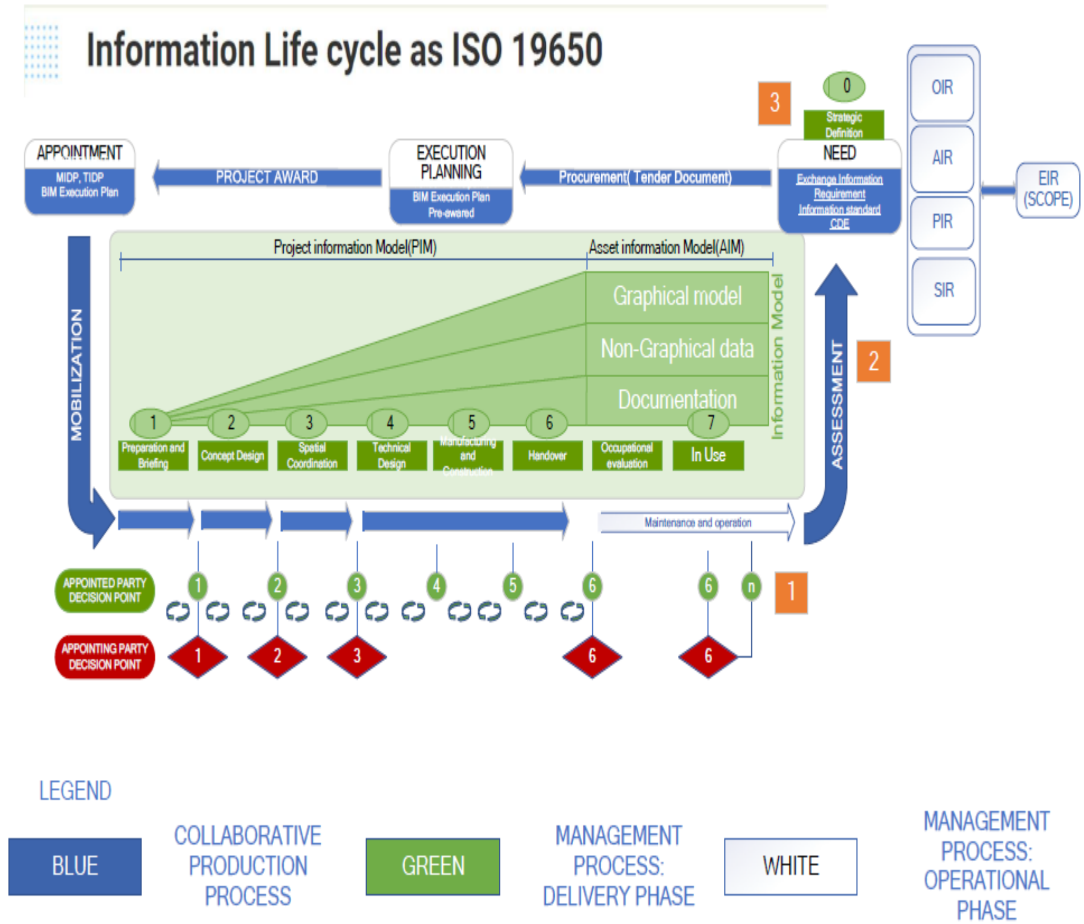


Figure 6 Overview and illustration of the information management process (ISO 19650-1:2018(E))

2.4.2 BIM Use Cases

BIM offers several key features that distinguish it from traditional 2D design and documentation methods in different phase of a construction project.

2.4.2.1 Planning and Design Stage

BIM has been increasingly adopted in the planning and design stages of construction projects due to its ability to facilitate collaboration, improve accuracy, and enhance the overall management of the building lifecycle.

Here are some of the key BIM use cases during planning and design stage (Ocean, 2023):

BIM Coordination: Multiple stakeholders contribute to the building model, enhancing collaboration and reducing conflicts.

Visualization: Offers a 3D visual representation of the project, aiding in design modifications and stakeholder communication.

Clash Detection: Identifies overlapping elements in the model to prevent construction issues

Cost Estimation: Facilitates accurate cost predictions based on the model's data.

Building Variants: BIM allows for the exploration of different building variations quickly and efficiently. This can be particularly useful when considering different design options and their implications on cost and construction.

Creation of Working Drawings: Traditionally a time-consuming task, BIM enhances the design and engineering process, facilitating the ability of architects, engineers, and other project stakeholders to merge and consolidate models, speeding up the drawing production phase.

Share Models with the Construction Team: Sharing models regularly with the construction team can save time and money on a project by allowing for greater collaboration and transparency. It enables all project participant insights and talents to be harnessed in one place.

Use Visual Software: The use of 3D models and virtual reality to visualize projects allows for a more comprehensive and "real world" view, which is often preferred by end clients such as building owners.

2.4.2.2 Construction Operation Stage

During the construction operation stage, BIM provides several use cases that enhance the efficiency and effectiveness of the construction process. Here are some of the key BIM use cases for this stage:

4D Scheduling: BIM integrates the project's time-related information, creating a 4D model that allows for detailed construction scheduling and sequencing. This helps in visualizing the construction process over time and managing deadlines more effectively.

Resource Management: It aids in the efficient planning and allocation of resources such as materials, labor, and equipment. BIM can track resource usage and help in optimizing the supply chain.

Quality Control: BIM ensures that construction adheres to the design specifications. It allows for continuous monitoring and quality checks, reducing the risk of errors and rework.

Safety Management: By simulating construction processes in BIM, potential safety hazards can be identified and addressed before they occur on-site, improving overall safety management**.**

Change Management: BIM facilitates the management of changes during construction. It provides a platform for tracking changes, assessing their impacts, and communicating them to all stakeholders.

Construction Documentation: BIM helps in generating accurate and up-to-date construction documents, which are essential for communication, compliance, and future reference**.**

As-Built Modeling: After construction, BIM can be used to create as-built models that reflect the completed project. This is valuable for facility management and future renovation projects.

2.4.2.3 Operation and Maintenance Stage

BIM has several use cases in the Operation and Maintenance (O&M) stage of a building's lifecycle, which can significantly improve efficiency and reduce costs. Here are some key BIM use cases for this stage:

Facility Management: Utilizes BIM data for efficient management of the building operations, including space management and asset tracking**.**

Predictive Maintenance: Leverages BIM data to predict maintenance needs and schedule repairs proactively.

Energy Analysis: Analyzes building performance data within the BIM model to optimize energy usage.

Lifecycle Management: Supports decision-making for building improvements and renovations over its lifecycle.

These use cases illustrate how BIM serves as a comprehensive tool throughout the entire lifecycle of a construction project, from initial planning to long-term maintenance.

2.4.3 Stages of BIM Maturity

According to ISO 19650, information management refers to the processes, activities, and controls that are implemented to effectively manage and exchange information throughout the lifecycle of a construction project in a BIM environment. The information management can be classified into four maturity stages as stage 0, stage1, 2 and 3. **Figure 7** illustrates how standards development, technological advancement and advanced information management lead to increased commercial benefits (ISO 19650-1:2018(E).

The ISO 19650 series is mostly applicable at Stage 2 maturity, but can also be utilized at Stages 1 and 3. Stage 2 maturity is often referred to as "BIM according to the ISO 19650 series". A federated information model is created by combining manual and automated information management methods. The information model encompasses all information provided by task teams related to an asset or project.

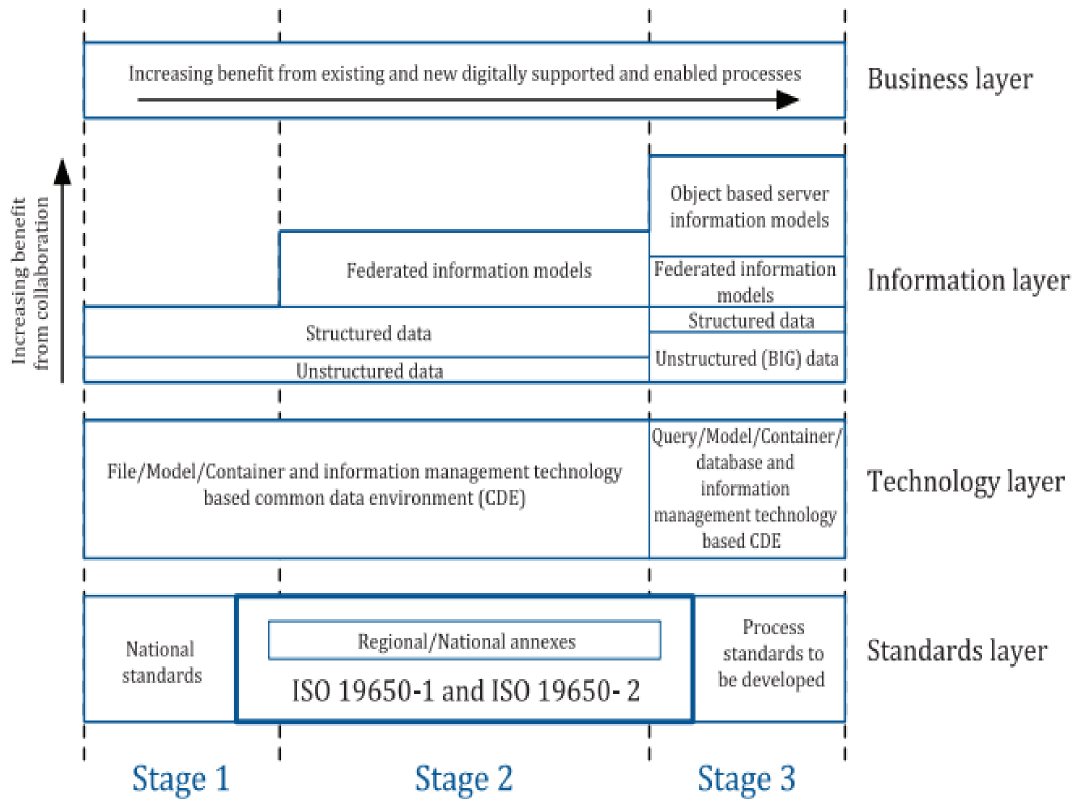


Figure 7 Stages of BIM Maturity according to ISO 19650-1:2018 (E)

2.4.4 BIM Software Tools

BIM software are integral to the modernization of the Architecture, Engineering, and Construction (AEC) industry by providing a digital representation of the physical and functional characteristics of a facility in a platform for enhanced collaboration, improved decision-making, and efficient project delivery. This software not only support the design and construction phases but also extend their utility to the operation and management of buildings (Parsamehr et al., 2023). Here are some of the BIM software tools:

2.4.4.1 BIM Authoring Tools

These tools are used to create and author detailed 3D models, including architectural, structural, and MEP (Mechanical, Electrical, Plumbing) designs.

Autodesk *Revit*

According to a survey conducted by McGraw Hill in 2019, Autodesk Revit is one of the most widely used BIM 3D modelling software applications in the architecture, engineering, and construction (AEC) industry (McGraw Hill, 2019).

Graphisoft ArchiCAD

ArchiCAD is a BIM software that focuses on architectural design and offers powerful 3D modeling capabilities (Graphisoft, 2024). It allows architects to create detailed 3D models, generate construction documentation, and perform clash detection.

2.4.4.2 BIM Coordination and Clash Detection Tools

These tools are designed to integrate multiple discipline-specific models, detect clashes, and coordinate the federated model.

Autodesk Naviswork

Navisworks is a project review software that allows BIM coordinators to combine and coordinate models from different disciplines (Autodesk, 2024). It enables clash detection, model coordination, and visualization of project data, helping BIM coordinators identify and resolve conflicts before construction.

Solibri Model checker

Solibri Model Checker is a BIM validation software that helps BIM coordinators ensure model quality and compliance with project requirements (Solibri, 2024). It offers rule-based checks, clash detection, and advanced model analysis capabilities, facilitating effective coordination and collaboration.

Trimble Tekla BIMsight

Tekla BIMsight is a collaborative BIM software that enables BIM coordinators to view, analyze, and communicate project information (Trimble, 2024). It allows for model coordination, clash detection, and issue tracking, streamlining the coordination process and enhancing collaboration among project stakeholders.

2.4.4.3 4D Scheduling, 5D Cost Estimation and Simulation Tools

These tools integrate time-related data into BIM models to simulate construction schedules and cost data into BIM models to perform quantity takeoffs and cost estimation.

Synchro Pro

Focuses on 4D construction planning, scheduling, and visualization (Bentley Systems, 2024).

Navisworks Manage

Supports 4D simulations by linking the construction schedule to model elements (Autodesk, 2024).

BEXEL Manager

BEXEL Manager is a comprehensive BIM software that offers a range of features specifically tailored for construction project management. It allows users to create and manage detailed virtual models of buildings or infrastructure projects, incorporating information about the physical components and their relationships (BEXEL Manager, 2024). By creating a comprehensive BIM model, project stakeholders can effectively coordinate and collaborate, leading to improved project outcomes.

BEXEL Manager provides software for project progress tracking. Users can monitor the status of various construction activities, track project milestones, and assess project performance against the planned schedule. This feature enables project managers to identify any delays or issues and take proactive measures to keep the project on track.

Furthermore, BEXEL Manager offers reporting capabilities, allowing users to generate customized reports based on the BIM model data. These reports can provide valuable insights into project progress, clash detection results, quantities and measurements, and other relevant information (Attia, 2020).

Figure 8 BIM Software Tools

The selection of an appropriate BIM software platform is a critical decision in construction project delivery, as it directly impacts efficiency, data integrity, collaboration, and the successful implementation of 4D and 5D BIM practices (Borrmann et al., 2016). Unlike traditional approaches that relied on isolated design and scheduling tools, BIM encompasses a range of software applications that support digital design, construction, and lifecycle management. Its effectiveness depends largely on aligning the chosen platform with the project's requirements and ensuring seamless data exchange across disciplines.

Open BIM vs. Closed BIM

Open BIM promotes collaboration and interoperability within the AEC sector by leveraging open data standards such as IFC (Industry Foundation Classes) and BCF (BIM Collaboration Format). These standards enable seamless information exchange across platforms, future proofing the project against technological changes and ensuring long-term accessibility (building SMART, 2020; Borrmann et al., 2016). Open BIM delivers significant benefits such as cost and time savings, improved collaboration, and greater freedom in selecting best-in-class technologies (Mercer, 2023; Kamila, 2024).

In contrast, Closed BIM operates within proprietary platforms, relying on vendor-specific formats that restrict data sharing and collaboration. This approach, sometimes called "lonely" BIM, often leads to information silos, inefficiency, and delays caused by fragmented data and workflow constraints (Borrmann et al., 2016; Mercer, 2023; Kamila, 2024). As a result, selecting an Open BIM approach is increasingly advocated as best practice for projects that require seamless multi-disciplinary integration.

Key Criteria for Selecting 4D/5D BIM Software

To fully realize the benefits of digital construction practices, BIM platforms must satisfy certain core requirements:

Core Functionality

Robust 4D BIM platforms enable the integration of three-dimensional elements with project schedules, including Gantt charts and CPM (Critical Path Method), allowing visual simulations of construction sequencing and real-time progress tracking (Eastman et al., 2011; Kymmell, 2008; Succar, 2009). Similarly, effective 5D BIM platforms must support quantity takeoff (QTO) and cost estimation based on model geometry and metadata, as well as cost-loaded scheduling, budget tracking, and cash-flow analysis (Monteiro & Martins, 2013; McPartland & Kouider, 2017; Azhar, 2011).

Interoperability

BIM platforms must integrate smoothly with other construction and design tools to enable seamless data exchange and collaboration. Compatibility with open standards (e.g., IFC), scheduling platforms such as Primavera P6 and MS Project, and cost estimation platforms like CostX and Sage Estimating is vital for achieving connected, multidisciplinary workflows (buildingSMART, 2020; Kymmell, 2008). Additionally, platforms that integrate with Common Data Environments (CDE) and support APIs and plugins can significantly reduce barriers to information exchange (Eastman et al., 2011; ISO 19650-1, 2018).

User-Friendliness

Ease of use is critical for promoting team adoption and ensuring the efficiency of digital workflows. Features such as an intuitive interface, high-quality 3D and 4D visualizations, and customizable dashboards and reporting tools help streamline collaboration and enable stakeholders to focus more on project outcomes than on software training (Kymmell, 2008; McPartland & Kouider, 2017; Succar, 2009).

Scalability

Modern construction projects vary greatly in complexity, making scalability a vital consideration. BIM platforms must efficiently manage large and complex models while providing cloud-based collaboration across distributed teams (Volk et al., 2014; Eastman et al., 2011). Scalability ensures that the software can evolve with the needs of the project and accommodate both small and large-scale construction environments.

Integration with Standards

Compliance with international standards is essential for achieving consistency and reliability across projects. BIM platforms must adhere to standards such as ISO 19650 for information management and be capable of managing varying levels of detail and information (LOD and LOI). Additionally, support for Information Delivery Specifications (IDS) allows for automated compliance checking, ensuring quality and reducing manual review efforts (ISO 19650-1, 2018; Borrmann et al., 2018).

Collaboration and Teamwork

Modern construction projects demand seamless teamwork across disciplines. BIM platforms must enable multi-user access and support robust clash detection and issue tracking features. By integrating schedule and cost data within the model, these platforms can reduce conflicts and help project teams manage both scheduling constraints and budget overruns more effectively (Eastman et al., 2011; Kymmell, 2008; McPartland & Kouider, 2017).

Cost-Effectiveness

Affordability is a vital consideration when selecting a BIM platform. Subscription-based or perpetual licensing options should be available to suit varying project and organizational needs. Training and support resources must be readily accessible to reduce implementation costs and minimize downtime during the software onboarding process (Kymmell, 2008; Eastman et al., 2011).

Security and Data Integrity

As project, data becomes increasingly digital and collaborative, robust security measures are essential. Encryption and access controls ensure the protection of sensitive information, while version control tools enable stakeholders to track changes and maintain a clear record of model revisions throughout the project lifecycle (ISO 19650-1, 2018; McPartland & Kouider, 2017).

2.4.5 BIM Dimensions

BIM dimensions refer to different aspects or levels of information and functionality that can be incorporated into a BIM model throughout the lifecycle of a construction project. The commonly recognized BIM dimensions are as follows (Eastman et al., 2011):

3D BIM: The first dimension of BIM represents the three-dimensional representation of the physical aspects of a building or structure. It involves creating a virtual model that accurately depicts the geometry, spatial relationships, and visual appearance of the project.

4D BIM: The second dimension of BIM introduces the element of time, adding a scheduling component to the 3D model. With 4D BIM, the model incorporates project scheduling information, allowing stakeholders to visualize the construction sequence, plan activities, and assess project timelines.

5D BIM: The third dimension of BIM incorporates cost-related information into the model. With 5D BIM, the model includes data on material quantities, costs, and project budgets. This enables stakeholders to estimate and track project costs, analyze cost impacts of design changes, and facilitate cost-effective decision-making throughout the project.

6D BIM: The fourth dimension of BIM involves incorporating sustainability and environmental data into the model. With 6D BIM, the model integrates information on energy performance, lifecycle analysis, and other environmental factors. This allows stakeholders to assess and optimize the project's environmental impact and sustainability aspects.

7D BIM: The fifth dimension of BIM extends the model to include operational and facility management information. With 7D BIM, the model incorporates data related to facility operation, maintenance, and asset management. This enables stakeholders to efficiently manage and maintain the facility throughout its lifecycle.

Each dimension builds upon the previous one, adding additional information and functionality to the BIM model. The aim is to enhance collaboration, improve decision-making, and optimize the design, construction, and ongoing management of the building or infrastructure project.

2.4.6 BIM Level of Development (LOD)

Levels of Development (LOD) serve as a standardized guideline for determining the level of detail and accuracy required in a Building Information Model (BIM) at various project phases. The level of development of BIM elements influences the integration of the 3D BIM model with time and cost considerations. LOD acts as a measure to specify the information content within model elements as the BIM model progresses through different stages. The main objective of LOD is to offer project stakeholders clear expectations regarding the information needed for BIM model development in design and construction phases (Autodesk, 2024). The American Institute of Architects (AIA) and the Associated General Contractors of America (AGC) have jointly established a widely used LOD framework that categorizes the building model into distinct levels as shown in **Table 1-1**.

Table 1-1 Table developed from (Approved Use Matrix by U.S. General Services Administration and AIA)

Model Content	LOD 100 (Conceptual design)	LOD 200 (Schematic Design)	LOD 300 (Design Development)	LOD 350 (Construction Documentation)	LOD 400 (Fabrication and Assembly)	LOD 500 (As-Built)
3D Model-based Coordination	Site level coordination	Major large object coordination	General object-level coordination	Generate construction documents (specifications and drawings)	Design certainty coordination	N/A
4D Scheduling	Total project construction duration. Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Complete construction sequencing and accurate scheduling	Fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring, etc.)	N/A
5D Cost Estimation	Conceptual cost allowance Example $/sf of floor area, $/hospital bed, $/parking stall, etc. assumptions on future content	Estimated cost based on measurement of the generic element (i.e. generic interior wall)	Estimated cost based on measurement of specific assembly (i.e. specific wall type)	Comprehensive cost estimation and quantity takeoff	Committed purchase price of specific assembly at buyout	Record cost
Program Compliance	Gross departmental areas	Specific room requirements	FF&E, casework, utility connections	Detailed 3D models with specific materials and products	N/A	N/A
Sustainable Materials	LEED strategies	Approximate quantities of materials by LEED categories	Precise quantities of materials with percentages of recycled and/or locally purchased materials	Accurate fabrication and assembly	Specific manufacturer selections	Purchase documentation
Analysis/Simulation	Strategy and performance criteria based on volumes and areas	Conceptual design based on geometry and assumed system types	Approximate simulation based on specific building assemblies and engineered systems	Coordinate multiple disciplines	Precise simulation based on the specific manufacturer and detailed system components	Commissioning and recording of measured performance

2.4.7 BIM Standards and Guidelines:

BIM standards and guidelines are established frameworks that provide guidance and recommendations for the implementation and use of BIM in construction projects. These standards and guidelines aim to promote consistency, interoperability, and best practices in open BIM processes and workflows (Bentley, 2021).

Here are some of the important BIM standards and guidelines:

IFC (Industry Foundation Classes): IFC is an open file format standard developed by building SMART for the exchange of BIM data between different software platforms. It enables interoperability by ensuring that information can be accurately exchanged and interpreted across different software applications.

Construction Operations Building Information Exchange (COBie): COBie is a standard for the exchange of information between different software applications in a construction project. It defines a structured format for capturing and delivering asset data and information throughout the project lifecycle (buildingSMART, 2020).

Classification Systems: Classification systems provide a standardized way of categorizing and organizing information in a BIM model. Examples include MasterFormat, UniFormat, and Omniclass, which provide consistent frameworks for organizing project information based on categories, functions, or attributes.

National BIM Standards: Many countries or regions have developed their own national BIM standards to address specific requirements and practices. Examples include the UK BIM Level 2 standards, the AIA, BIM standards in the United States, and the Singapore BIM Guide.

ISO 19650: ISO 19650 is an international standard that provides a framework for managing information throughout the lifecycle of a construction project using BIM. It outlines principles and requirements for information management, collaboration, and the use of a Common Data Environment (CDE).

The ISO 19650 series consists of 6 parts and summarized on **Table 1-2**.

Table 1-2 ISO 19650 Series Summarized

ISO parts	Content	Key points
ISO 19650-Part 1	Concepts and principles	Emphasize collaboration, structured information, and clear requirements, while also introducing the concept of the CDE as a central repository.
ISO 19650-Part 2	Delivery phase of assets	Covers Exchange Information Requirement (EIR) and Asset Information Requirement (AIR) in the delivery phase of a project, outlining the responsibilities of all parties involved in managing and ensuring data quality.
ISO 19650-Part 3	Operation phase of assets	Focus on post-delivery information management, maintenance, asset management and accurate information for efficient operations.
ISO 19650-Part 4	Information exchange	Covers the requirements for the exchange of information throughout the asset life cycle, specifies format, structures, and quality of exchanges, ensures consistency, introduces templates and covers data security.
ISO 19650-Part 5	Security-minded approach to information management	Covers security aspects of information management in the context of BIM, guidelines for a security-minded approach, mitigating risks, protecting sensitive data and ensuring secure information exchanges.
ISO 19650-Part 6	Health and safety	Defines collaborative sharing and digitalization of health and safety information. Prioritizes safety critical risks and management framework

2.4.8 BIM Workflow as per ISO 19650

The implementation of Building Information Modelling (BIM) within the architecture, engineering, and construction (AEC) sector is standardized and structured by the ISO 19650 series. These standards define a collaborative and information-centric approach across the built asset's lifecycle from initial concept through design and construction, and extending to operation and maintenance (BSI, 2018; BS EN ISO 19650-1, 2019). The workflow prescribed by ISO 19650 is organized around a clearly defined information delivery cycle that promotes accountability, consistency, and quality across all stakeholders (ISO 19650-1, 2018).

1. Assessment and Need Identification

At the project initiation stage, the appointing party (e.g., client or owner) defines its information requirements, including the Organizational Information Requirements (OIR), Asset Information Requirements (AIR), and Project Information Requirements (PIR) (BS EN ISO 19650-1, 2019). These requirements enable a thorough assessment of project needs and help determine if a project is necessary and feasible.

2. Invitation to Tender

Based on these requirements, the appointing party develops Exchange Information Requirements (EIR), specifying the information deliverables required their format, and their timing. The EIR form a pivotal part of the tender process, allowing suppliers to respond with a pre-contract BIM Execution Plan (pre-BEP), demonstrating how their team will deliver information throughout the project lifecycle (BS EN ISO 19650-2, 2019).

3. Appointment and Planning

Following the tender review, a supplier or lead appointed party is selected. This party develops a post-contract BEP, aligning with the EIR and detailing methods, technologies, and protocols for information delivery. A Master Information Delivery Plan (MIDP) is established, supported by Task Information Delivery Plans (TIDPs), to clearly define responsibilities, deadlines, and the information to be delivered by each party (BS EN ISO 19650-2, 2019).

4. Mobilization

During mobilization, the project team sets up the Common Data Environment (CDE) a central digital repository for information exchange and confirms roles and responsibilities within the project team. The Lead Appointed Party is responsible for managing information flow, supported by Task Teams that produce and manage discipline-specific data (BS EN ISO 19650-1, 2019).

5. Collaborative Production of Information

The project teams and progresses through four status levels within the CDE develop information:

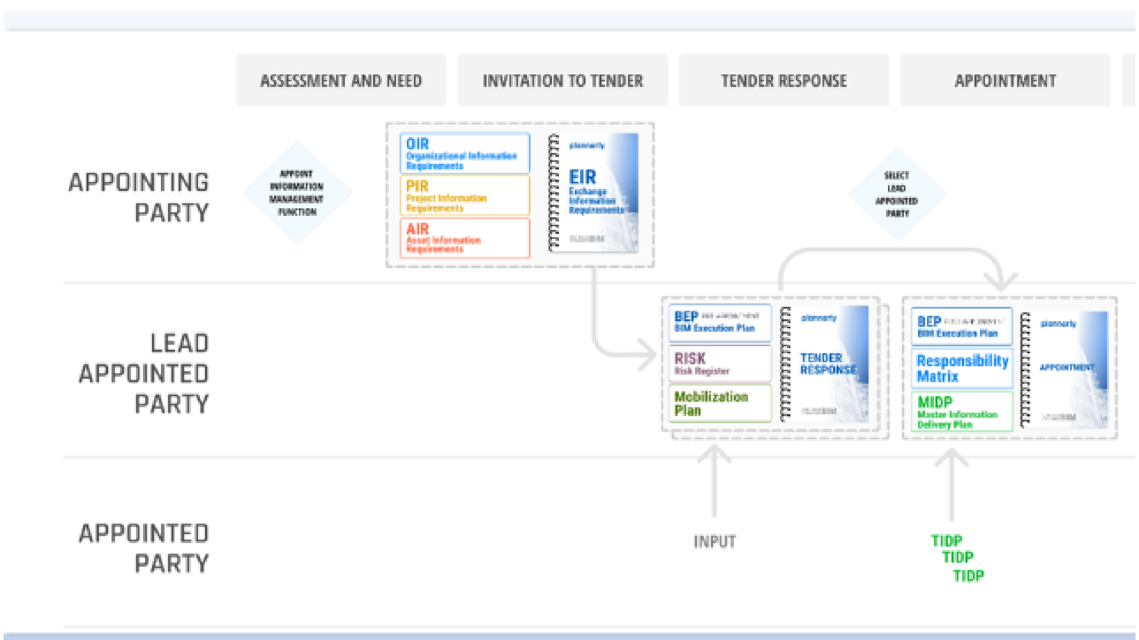
- Work in Progress (WIP): Information under development
- Shared: Checked and approved information available for review and coordination
- Published: Final information approved for use by stakeholders
- Archived: Information stored for future reference and compliance verification (BS EN ISO 19650-1, 2019)

6. Information Model Delivery

The compiled and verified Project Information Model (PIM) is delivered in accordance with the requirements set out in the EIR and BEP. The PIM includes 3D models, data sheets, schedules, and supporting documents required for design, construction, and handover (BS EN ISO 19650-2, 2019).

7. Project Close-out and Handover

At the end of the construction phase, the information transitions to an Asset Information Model (AIM). The AIM contains all relevant data required for operation, maintenance, and future refurbishments, supporting long-term asset performance and facility management (BS EN ISO 19650-3, 2020).



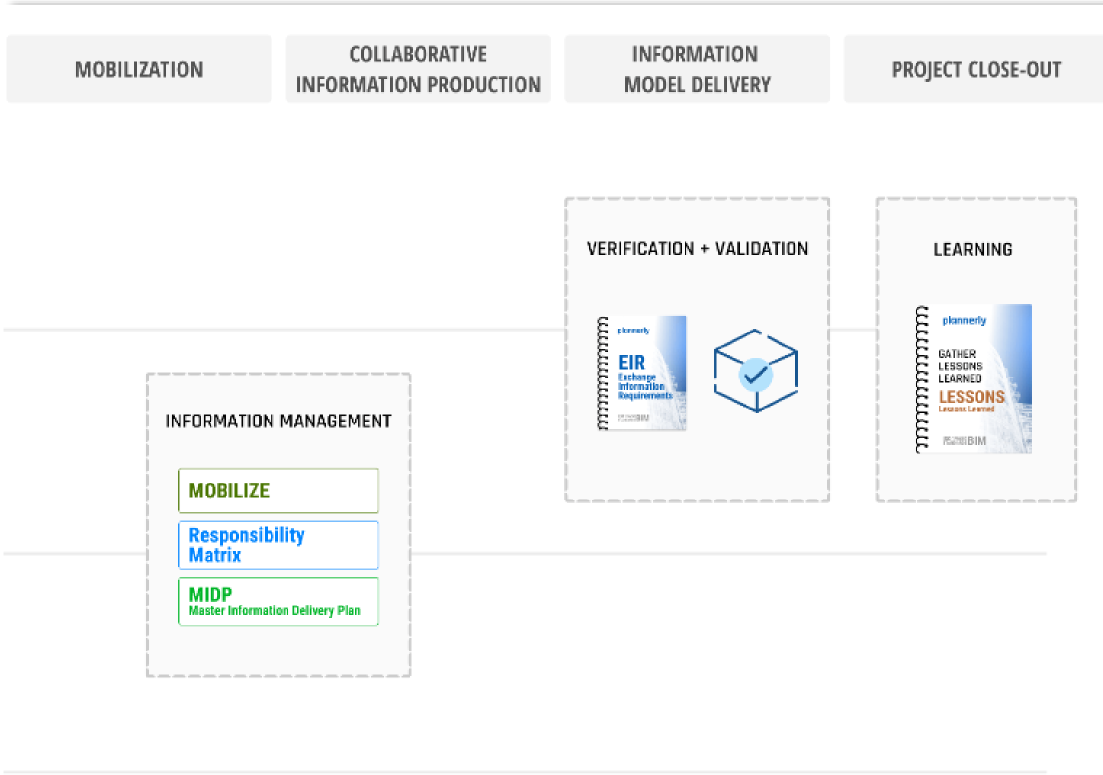


Figure 9 Information management throughout the asset life cycle based on ISO 19650-1 (2017) Source: Plannerly.com

2.5 4D BIM

2.5.1 Introduction

4D Building Information Modeling (BIM) is an emerging technology that links 3D models with construction schedule data to simulate sequencing over time (Heesom & Mahdjoubi, 2004). This paper provides an overview of 4D BIM and its applications supported by current literature.

2.5.2 4D BIM Concept

In traditional planning, schedules are separately mapped without reference to design geometry (Dawood et al., 2011). 4D BIM overcomes limitations by integrating schedules as the fourth dimension directly into 3D models through activities coded to model elements (Song et al., 2009). Time-space coordination among construction resources and workspaces is thereby optimized (Chavada et al., 2012).

2.5.3 Application of 4D BIM

2.5.3.1 Construction Scheduling

Automated building component tracking simplifies schedule development from linked model activities (Heesom & Mahdjoubi, 2004). Schedule updates are instantly reflected in visualizations reducing errors (Dawood et al., 2011).

2.5.3.2 Site Utilization Planning

4D simulations aid layout optimization through visual reviews of space and resource requirements at different stages. Clash detections ensure smooth workflow transitions (Song et al., 2009).

2.5.3.3 Progress Monitoring

Variance identification is improved relating planned schedules extracted from models to real inputs captured digitally on-site (Solnosky et al., 2015).

2.5.3.4 Safety planning

Spatial risk assessments leverage 4D simulations to evaluate hazards from temporary structures, material movements, etc. (Chavada et al., 2012).

2.5.3.5 Dispute Mitigation

Time-related claims are minimized through referencing schedules authenticated within models during executions (Heesom & Mahdjoubi, 2004).

2.6 5D BIM

2.6.1 Introduction

5D BIM is an advanced approach to construction project management that incorporates the dimension of cost into the traditional 3D BIM model. It involves the integration of cost-related data and analysis with the spatial and temporal components of the model.

2.6.2 5D BIM Concept

The core concept of 5D BIM revolves around the integration of cost data with the 3D BIM model. This integration allows project stakeholders to visualize and analyze the cost implications of design decisions, changes, and construction activities. Cost-related information such as material quantities, labor rates, equipment costs, and project schedules are linked to the BIM model to generate accurate and real-time cost estimations. 5D BIM enhances project visualization, cost estimation, budget tracking, and cost optimization throughout the project lifecycle (Eastman et al., 2011).

2.6.3 Application of 5D BIM

2.6.3.1 *Cost Estimation and Budgeting:*

5D BIM enables accurate cost estimation and budgeting by integrating cost data with the detailed design and construction sequencing. This allows for more accurate and reliable cost predictions, reducing the likelihood of budget overruns (Eastman et al., 2011). 5D BIM helps in improving the quality of construction projects by enabling accurate quantity estimation and better planning (Kristijan, 2023)

2.6.3.2 *Quantity Takeoff and Material Management:*

5D BIM facilitates automated quantity takeoff and material management. Eastman et al. (2011) state that 5D BIM allows for the extraction of quantities directly from the model, enabling more efficient material ordering and reducing waste.

2.6.3.3 Lifecycle Cost Analysis:

5D BIM allows for lifecycle cost analysis, considering the costs of construction, operation, and maintenance. According to Becerik-Gerber et al. (2010) integrating real-time cost information into the BIM model supports lifecycle cost analysis and informed decision-making.

2.6.3.4 *Cost Optimization:*

5D BIM facilitates cost optimization by allowing stakeholders to explore different design alternatives and evaluate their cost implications. By visualizing and analyzing cost scenarios, project teams can make informed decisions that balance design intent and cost considerations (Eastman et al., 2011).

2.6.3.5 *Efficient Cost Tracking and Control:*

5D BIM supports efficient cost tracking and control throughout the project lifecycle. By continuously updating the cost-related information in the BIM model, project teams can monitor actual costs against the budget, identify deviations, and make timely adjustments to keep the project on track (Eastman et al., 2011).

These applications demonstrate the versatility of 5D BIM in various aspects of construction project management, including cost estimation, quantity takeoff, project scheduling, clash detection, and lifecycle cost analysis.

2.7 4D/ 5D Construction Project Management vs Traditional Construction Project Management

2.7.1 4D/5D Construction Project Management:

4D/5D construction project management integrates the dimension of time (4D) and cost (5D) into the project management process. It involves the use of Building Information Modeling (BIM) technology to create a visual representation of the construction project's schedule and cost components (Eastman et al., 2011).

Cost features from cost data are either integrated into model objects or linked to estimate software for completely exchangeable data. As a result, the model serves as a store for cost estimators' data. According to Stanley and Thurnell (2014), extracting costing information and visualizing the 3D model reduces assumptions about design. The costs are produced with less errors, increased precision, and greater reliability.

Additionally, the software's parametric capabilities ensures that changes in parameters result in direct alteration of the model as well as other elements such as bill of quantities and sections. Accurate measurements reveal the budget impact of design alterations (Doumbouya et al., 2017). As a result, when design modifications occur, the integrated 5D BIM model automatically updates time and cost features. Using this paradigm allows the design team to evaluate possibilities, assess the impact of modifications, and track scope and cost during early phases (Bryde et al., 2013).

Moreover, BIM-based planning enhances the quality of the design by facilitating the creation of a comprehensive digital model, coordinating needs, and analyzing design choices (Borrmann, et al., 2018). In order to achieve these advantages, the use of BIM causes the design process to become more intensive early on as compared to the traditional planning method, as **Figure 10** illustrates. Additionally, a BIM-based planning process takes advantage of the chance to control costs early on by requiring less expensive design modifications.

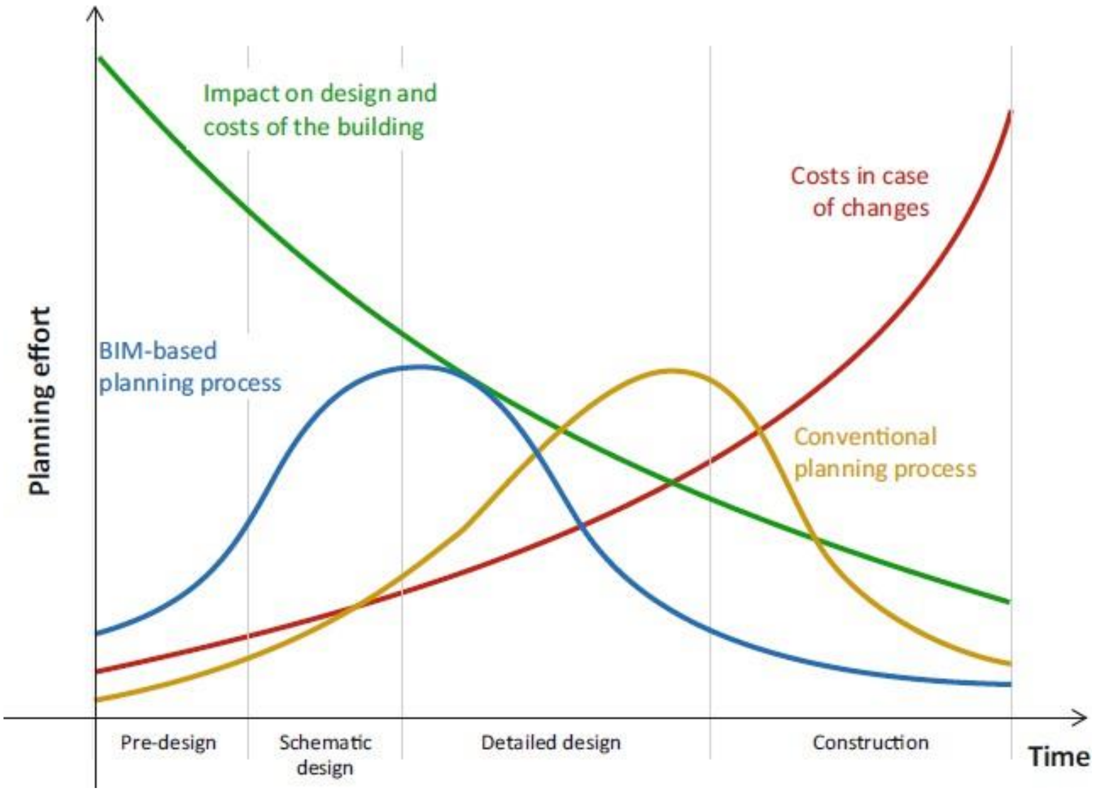


Figure 10 BIM-based planning process in comparison to the conventional planning process. (Based on MacLeamy 2004 as cited in Borrmann, et al., 2018)

2.7.2 Traditional Construction Project Management:

Traditional construction project management typically relies on manual processes, 2D drawings, and separate documents for planning, scheduling, and cost estimation. The focus is primarily on project coordination and control without the integrated visualization of time and cost aspects (Eastman et al., 2020).

In traditional project management, scheduling is often done using Gantt charts or spreadsheets, which may not provide a visual representation of the construction sequence. This can make it difficult to identify scheduling conflicts and visualize the impact of changes on the project timeline (Eastman et al., 2020).

Traditional project management involves separate cost estimation and control processes. Cost estimation may rely on manual calculations, which can be time-consuming and prone to errors. Cost control may involve manual tracking and analysis of costs, potentially leading to delayed or inaccurate decision-making (Eastman et al., 2020).

In summary, 4D/5D construction project management integrates time and cost dimensions into the project management process using BIM technology, enabling visual representation, enhanced coordination, and data-driven decision-making. In contrast, traditional construction project management relies on separate processes for scheduling and cost estimation, with limited visual representation and integration of time and cost aspects.

2.7.3 4D/5D BIM Practice in Other Countries:

2.7.3.1 United States

The United States has been at the forefront of BIM adoption, with various studies highlighting its benefits. For instance, Eastman et al. (2011) discuss improved project visualization, clash detection, and cost estimation as key advantages of 4D BIM implementation. The US has also developed BIM standards, such as the National BIM Standard-United States (NBIMS-US), to promote interoperability and consistency.

2.7.3.2 United Kingdom

The UK has made significant progress in BIM implementation, supported by government initiatives. Research by Arayici et al. (2011) highlights improved project coordination, reduced errors, and enhanced collaboration resulting from 4D BIM implementation. The UK has also mandated BIM utilization in government projects through the UK BIM Level 2 requirement.

2.7.3.3 Singapore

Singapore has been proactive in promoting BIM adoption. Research by Wong et al. (2013) emphasizes the benefits of 4D BIM, including improved construction planning, sequencing, and resource management. Singapore has implemented the Building and Construction Authority (BCA) BIM e-submission system, which requires BIM use in government projects.

2.7.3.4 United Arab Emirates (UAE)

The UAE has made significant strides in BIM implementation, particularly in the construction sector. Research by Alshawi et al. (2013) highlights the benefits of 4D BIM, including improved project visualization, clash detection, and construction sequencing. The UAE has also implemented BIM requirements in government projects, such as the Dubai Municipality BIM mandate.

2.7.3.5 Australia

Australia has been a leader in promoting BIM adoption and has developed comprehensive guidelines and standards. Research by Succar (2009) emphasizes the potential benefits of 4D BIM, such as enhanced project scheduling, improved construction sequencing, and better visualization. Australia has also used BIM extensively in major infrastructure projects, such as the Sydney Opera House renovation.

2.7.3.6 China

China has witnessed rapid growth in BIM implementation, driven by government policies and initiatives. Research by Deng et al. (2017) highlights the advantages of 4D BIM, such as improved project coordination, clash detection, and construction simulation. China has also established BIM standards and requirements for public projects.

2.7.4 BIM Practice in Ethiopia:

The adoption and implementation of Building Information Modeling (BIM) in Ethiopia have been gradually gaining traction, with several organizations and corporations beginning to integrate BIM into their construction practices.

2.7.4.1 Based on Industry Practices

This section provides an overview of the BIM practices of key organizations in Ethiopia, including the Construction Management Institute, Ethiopian Construction Works Corporation, and Ethiopian Engineering Corporation.

Construction Management Institute (CMI) BIM Practice

The Construction Management Institute (CMI) plays a pivotal role in advancing digitalization within the Ethiopian construction sector, serving as both a regulator and a catalyst for modern project delivery practices. Established as a government-affiliated body, CMI aims to enhance project management practices, build institutional and technical capacity, and support the adoption of innovative technologies across the construction lifecycle (Ethiopian Construction Management Institute, 2021). Its responsibilities align closely with the objectives of Building Information Modeling (BIM), making it an important enabler for the digital transformation of the sector.

One of CMI's core contributions lies in policy formulation and awareness generation. As BIM gains global recognition for its ability to integrate design, construction, and operation, CMI promotes its value across Ethiopian construction projects and advocates for policies that embed BIM within national construction standards (Belay et al., 2021). The institute actively works with stakeholders to highlight BIM's benefits including improved planning, enhanced collaboration, and increased cost and schedule predictability and encourages its adoption in both public and private projects.

Capacity building is another key area of CMI's engagement. Through training programs, workshops, and seminars, CMI develops technical competencies required for effective BIM implementation. These efforts focus on equipping construction professionals including project managers, engineers, architects, and contractors with the knowledge and practical skills necessary for utilizing BIM platforms effectively such initiatives foster a culture of collaboration and digital literacy within the sector (Berhanu, 2024).

Moreover, CMI plays a pivotal role in standardization and aligning BIM with international practices, including the ISO 19650 framework. The institute developed a road map for adoption and implementation BIM technology for the Ethiopian Architectural, Engineering and Construction (AEC) industry (Feleke, 2025). In doing so, it promotes a structured approach to information management and encourages digitalization across all phases of the construction lifecycle.

Through its facilitation role, CMI acts as a bridge between government institutions, academia, and the private sector. It supports pilot projects to test the benefits and feasibility of BIM within the Ethiopian construction context, allowing stakeholders to assess its impact on project performance and identify barriers to adoption. The results of such pilot studies provide valuable insights for refining BIM implementation strategies and integrating digital technologies into mainstream practice. CMI's ongoing role in guiding, facilitating, and promoting BIM adoption positions it as a central figure in advancing digital transformation within Ethiopia's construction sector.

Ethiopian Construction Works Corporation (ECWC) BIM Practice

The Ethiopian Construction Works Corporation (ECWC), one of the largest public construction entities in Ethiopia, has begun incorporating BIM into its project management processes. ECWC primarily uses BIM for 3D modeling and visualization, which has improved design coordination and clash detection in its projects. The organization has also explored the use of 4D BIM for scheduling and 5D BIM for cost estimation, although these practices are not yet fully institutionalized. ECWC faces challenges such as a lack of skilled personnel, high costs of BIM software, and resistance to change from traditional project management methods. Despite these challenges, ECWC has recognized the potential of BIM to improve project efficiency and is working towards its broader adoption (Abebaw, 2024)

Ethiopian Engineering Corporation (EEC) BIM Practice

The Ethiopian Engineering Corporation (EEC) has begun integrating BIM into its engineering and construction projects, primarily focusing on 3D modeling for design coordination and visualization. EEC has also experimented with 4D BIM for project scheduling, which has helped improve timeline management and reduce delays in some of its projects. However, the adoption of 5D BIM for cost estimation and control remains limited. EEC has identified several barriers to BIM adoption, including a lack of standardized BIM workflows, insufficient training programs, and limited government support. To address these challenges, EEC is collaborating with academic institutions and industry associations to promote BIM education and research (Mengist, 2024).

The BIM practices of these organizations reflect the broader trends and challenges of BIM adoption in Ethiopia. While there is growing recognition of BIM's potential to improve project outcomes, its implementation is still in its infancy. Key challenges include a lack of skilled professionals, high initial costs, and resistance to change. Despite these obstacles, organizations like CMI, ECWC, and EEC are making significant strides in integrating BIM into their workflows, with a focus on capacity building, pilot projects, and collaboration with international partners. These efforts are laying the foundation for the wider adoption of BIM in Ethiopia's construction industry.

2.7.4.2 Based on Researches

The implementation of Building Information Modeling (BIM) in construction project management has been the subject of several studies, in the Ethiopian construction sector. This section reviews relevant literature to provide insights into the benefits, challenges, and current state of BIM adoption, with a focus on its application in 4D (time) and 5D (cost) dimensions.

The study by Tesfaye (2021) on "Design Management Using BIM: Case of Pilot Projects in Addis Ababa" highlighted the significant improvements BIM brings to design management. The research demonstrated that BIM enhances communication, collaboration, visualization, and design coordination, while also integrating constructability and maintainability concepts. The study emphasized the advantages of model-based material takeoff, which allows for faster and more accurate cost estimation compared to manual quantification. Furthermore, scheduling and simulation using BIM toolsets were found to improve visualization, communication, and project tracking. However, the projects studied failed to adequately address critical path analysis and other scheduling details.

Girma (2023) investigated the role of BIM in project management in the study titled "Building Information Modelling (BIM) and Project Management: The Role of BIM for the Success of Building Construction Projects; The Case of Ethiopian Engineering Investment Group (EEIG) Construction." The findings revealed that BIM significantly impacts the success of building construction projects, particularly through the use of 3D BIM for visualization and clash detection. However, the study noted that the implementation of 4D and 5D BIM, which relate to time and cost estimation, is still in its early stages. The research recommended that the company enhance its adoption of 4D and 5D BIM to improve cost and time estimation, which are critical factors in project management.

Belete (2020) conducted a phenomenological study titled "Perceptions Towards BIM Adoption Barriers and Strategies in Addis Ababa Construction Industry." The study focused on identifying barriers to BIM adoption and strategies to overcome them. The researcher suggested that presenting the benefits of BIM in meaningful numerical figures, such as comparisons showing cost and time savings, could help attract stakeholders and encourage adoption. The study emphasized that general case studies are insufficient and that more specific, data-driven examples are needed to demonstrate BIM's value.

Belay et al. (2021) conducted an empirical study on enhancing BIM implementation in the Ethiopian public construction sector. The study identified five latent benefit components of BIM adoption: project management, technical, economic, lifecycle, and contractual benefits. Additionally, four latent barrier components were identified: legal and contractual issues, process-related challenges, cultural and organizational resistance, and government-related barriers. The study highlighted the need for qualitative research to provide additional perspectives and suggested that future studies focus on specific project types, such as road, water, or residential projects, to better understand the variability of BIM adoption.

Desbalo (2020) investigated the perceived benefits and barriers of BIM adoption in Ethiopia's architecture, engineering, and construction (AEC) sectors. The study found that the perception of BIM technology in the Ethiopian construction industry is generally positive, but its implementation remains in its infancy. The top-ranked benefits of BIM included its ability to provide easy quantity and cost estimates, timely integration and data sharing, enhanced digital project documentation, and the production of as-built documents throughout the project lifecycle. The study recommended further research using case studies and other instruments to enhance knowledge in BIM and information technology applications in Ethiopia.

Belay et al. (2021) also conducted a comparative analysis of BIM adoption models between the public and private sectors. The study identified key drivers of BIM adoption at different stages and emphasized the importance of intersectional efforts to reinforce BIM adoption. The research suggested future studies focus on BIM adoption case studies, project budgets, organizational capacity, and comparative analyses of project types, including contract amounts and delivery methods. The study highlighted the importance of capturing both theoretical and practical perspectives to understand the unique features of the Ethiopian construction business environment.

G/egziabher (2023), in the study "Role of Building Information Modeling (BIM) on Project Success and Its Implementation Challenges: The Case of Ovid Construction PLC," focused on identifying BIM implementation processes within the organization. The findings revealed that BIM processes had not been fully implemented, and the study emphasized the need for large-scale research to examine BIM's impact on project management processes, including scheduling, cost estimation, risk management, sustainability, and communication.

Girma (2017), in the study "5D Planning, Scheduling and Control of Construction Projects by Integrating Project Management Software & GIS," highlighted the limited use of 4D technologies in the construction industry. The study identified challenges such as the difficulty of use and modification, the inability to segregate spatial and non-spatial information, and the lack of standard procedures for using 4D technologies. Despite the advantages of 5D models for planning and scheduling, the industry remains reliant on traditional methods, limiting the potential benefits of BIM.

2.8 Challenges and Opportunities of 4D/5D BIM Implementation:

The implementation of 4D (time) and 5D (cost) BIM in construction project management offers significant opportunities for improving project outcomes but also comes with notable challenges.

2.8.1 Challenges of 4D BIM Implementation

High Initial Costs

One of the most significant barriers to 4D/5D BIM adoption is the high initial cost of software, hardware, and training. Advanced BIM tools, such as Autodesk Navisworks and Synchro Pro, require substantial financial investment, which can be prohibitive for small and medium-sized enterprises (SMEs) (Monteiro & Martins, 2013). Additionally, the cost of hiring or training skilled professionals to operate these tools adds to the financial burden.

Lack of Skilled Workforce

The successful implementation of 4D/5D BIM requires skilled professionals who are proficient in both BIM tools and project management. However, there is a shortage of such professionals, particularly in developing countries. This skills gap limits the ability of organizations to fully leverage the benefits of 4D/5D BIM (Ghaffarianhoseini et al., 2017).

Resistance to Change

Many construction firms are hesitant to transition from traditional project management methods to BIM-based workflows. This resistance to change is often rooted in a lack of understanding of BIM's benefits and a reluctance to adopt new technologies (Hartmann et al., 2012). Organizational inertia and cultural resistance can significantly slow down the adoption process.

Interoperability Issues

The integration of 4D and 5D BIM often involves combining data from multiple software platforms, such as Revit, Navisworks, and Primavera. Interoperability issues between these platforms can lead to data loss, inefficiencies, and errors, making it challenging to create a seamless workflow (Lu et al., 2014).

Lack of Standardization

The absence of standardized processes and guidelines for 4D/5D BIM implementation creates inconsistencies in its application across projects. This lack of standardization can lead to inefficiencies and limit the scalability of BIM adoption (Cao et al., 2015).

2.8.2 Opportunities of 4D/5d BIM Implementation

Enhanced Project Visualization

4D BIM enables project teams to visualize construction sequences over time, improving communication and collaboration among stakeholders. This enhanced visualization helps identify potential scheduling conflicts early in the project lifecycle, reducing delays and improving efficiency (Smith et al., 2020).

Improved Cost Management

5D BIM integrates cost data into the BIM model, allowing for real-time updates as design changes occur. This dynamic cost management improves the accuracy of cost estimates and enables better budget control, reducing the risk of cost overruns (Johnson & Lee, 2019).

Risk Mitigation

The ability of 4D BIM to simulate construction processes and identify potential risks before construction begins is a significant advantage. By visualizing and analyzing construction sequences, project teams can develop effective risk mitigation strategies, improving overall project outcomes (Hartmann et al., 2012).

Lifecycle Cost Analysis

5D BIM provides a platform for conducting lifecycle cost analysis, enabling project teams to evaluate the long-term financial implications of design decisions. This capability supports sustainable construction practices and ensures the financial viability of projects (Reddy, 2012).

Increased Stakeholder Engagement

The use of 4D and 5D BIM fosters better communication and collaboration among stakeholders by providing a shared platform for project data. This increased engagement leads to more informed decision-making and improved project outcomes (Ghaffarianhoseini et al., 2017).

The implementation of 4D and 5D BIM presents both challenges and opportunities for the construction industry. While high initial costs, lack of skilled personnel, and interoperability issues pose significant barriers, the potential benefits of enhanced visualization, improved cost management, risk mitigation, and stakeholder engagement make 4D/5D BIM a transformative tool for project management. Addressing the challenges through training, standardization, and government support can unlock the full potential of 4D/5D BIM in the construction sector.

2.9 Empirical Review

The application of 4D (time) and 5D (cost) BIM in construction project management has been extensively studied in various contexts. These dimensions of BIM are critical for improving project scheduling, cost estimation, and overall project efficiency. Below are some reliable empirical studies that highlight the benefits, challenges, and practical applications of 4D and 5D BIM in construction project management.

Babič et al. (2010) conducted an empirical study on the application of 4D BIM for construction project scheduling and visualization. The study demonstrated that 4D BIM enhances project planning by integrating time-related data into the 3D model, enabling stakeholders to visualize the construction sequence over time. The research found that 4D BIM improves communication among project teams, reduces scheduling conflicts, and facilitates better decision-making. The study also highlighted the challenges of implementing 4D BIM, including the need for skilled personnel and the integration of scheduling software with BIM tools.

Monteiro and Martins (2013) explored the application of 5D BIM for cost estimation and budget control in construction projects. The study revealed that 5D BIM provides accurate and dynamic cost estimates by linking cost data to the 3D model. This integration allows project managers to track changes in design and their impact on project costs in real-time. The research also emphasized the importance of standardizing cost data and training professionals to maximize the benefits of 5D BIM.

Ghaffarianhoseini et al. (2017) conducted a comprehensive review of the benefits of 4D and 5D BIM in large-scale construction projects. The study highlighted that 4D BIM improves project scheduling by enabling real-time updates and visualizations of construction sequences. Similarly, 5D BIM enhances cost management by providing accurate cost forecasts and facilitating better financial decision-making. The research also identified barriers to adoption, such as high initial costs, lack of expertise, and resistance to change.

Hartmann et al. (2012) presented a case study on the use of 4D BIM for risk management in construction projects. The study demonstrated that 4D BIM helps identify potential risks during the planning phase by visualizing construction sequences and detecting scheduling conflicts. The integration of risk data with the BIM model allowed project managers to develop mitigation strategies and improve project outcomes. The research concluded that 4D BIM is a valuable tool for proactive risk management in construction.

Reddy (2012) investigated the use of 5D BIM for lifecycle cost analysis in construction projects. The study found that 5D BIM enables project teams to evaluate the long-term financial implications of design decisions by integrating lifecycle cost data into the BIM model. This capability allows for more informed decision-making and helps ensure the financial sustainability of construction projects. The research also emphasized the need for standardized data formats and interoperability among BIM tools to fully realize the benefits of 5D BIM.

Lu et al. (2014) conducted a comparative analysis of 4D and 5D BIM adoption in construction projects across different regions. The study revealed that while 4D BIM is widely used for scheduling and visualization, the adoption of 5D BIM for cost management is less common due to the complexity of integrating cost data with BIM models. The research highlighted the need for industry-wide standards and training programs to address these challenges and promote the broader adoption of 4D and 5D BIM.

Elghaish et al. (2022) present a framework for the automatic production and optimization of 4D BIM models that combines ABC, IPD, and BIM. Using a case study, they test their methodology and demonstrate that the suggested multi objective optimization1 results in a cost savings of 22.86%.

Cao et al. (2015) explored the practices and effectiveness of 4D and 5D BIM in construction projects in developing countries. The study found that while BIM adoption is still in its early stages in these regions, the use of 4D and 5D BIM has shown significant potential for improving project outcomes. The research emphasized the importance of government support, industry collaboration, and capacity-building initiatives to overcome barriers to adoption.

The empirical studies reviewed demonstrate that 4D and 5D BIM offer significant benefits for construction project management, including improved scheduling, cost estimation, risk management, and lifecycle cost analysis. However, challenges such as high implementation costs, lack of expertise, and interoperability issues remain barriers to widespread adoption.

Future research should focus on addressing these challenges and exploring strategies for scaling up the use of 4D and 5D BIM, particularly in developing countries like Ethiopia.

2.10 Summary of Literature and Research Gap

2.10.1 Summary of the Literature Review

The literature review highlights the transformative potential of 4D (time) and 5D (cost) Building Information Modeling (BIM) in construction project management. It explores the theoretical framework, traditional construction project management practices, and the adoption of BIM in global and Ethiopian contexts. Below is a summary of the key points:

1. **Theoretical Framework of Construction Project Management**

Construction project management (CPM) involves planning, coordination, and control to achieve project objectives related to time, cost, and quality (Walker, 2015; Smith, 2003).

Traditional CPM methods face challenges such as fragmented workflows, lack of integration, and inefficiencies in scheduling, cost estimation, and risk management (Sears et al., 2008; Olawale & Sun, 2010)

2. **Traditional Construction Project Management Challenges**

Traditional methods rely on linear, document-centric processes, which are prone to errors, delays, and inefficiencies.

Manual scheduling tools like Gantt charts and CPM lack feedback mechanisms, while cost estimation methods are time-consuming and error-prone (Alzraiee et al., 2015; Eastman et al., 2011).

3. **Role of BIM in Construction Project Management**

BIM integrates design, scheduling, and cost data into a single digital model, enhancing project visualization, coordination, and decision-making (Eastman et al., 2011).

4D BIM links time-related data to 3D models for improved scheduling and sequencing, while 5D BIM incorporates cost data for dynamic cost estimation and control.

4. **Global Adoption of 4D/5D BIM**

Countries like the United States, United Kingdom, Singapore, and China have demonstrated the benefits of 4D/5D BIM in improving project outcomes through better scheduling, cost management, and risk mitigation (Arayici et al., 2011; Wong et al., 2013; Deng et al., 2017).

Challenges include high initial costs, lack of skilled personnel, interoperability issues, and resistance to change.

5. BIM Adoption in Ethiopia

The Ethiopian construction industry is gradually adopting BIM, with organizations like the Ethiopian Construction Works Corporation (ECWC) and Ethiopian Engineering Corporation (EEC) exploring its applications.

Studies indicate that BIM adoption is still in its infancy, with limited use of advanced dimensions like 4D and 5D BIM. Barriers include high costs, lack of expertise, and insufficient government support (Belay et al., 2021; Mengist, 2024).

6. Benefits of 4D/5D BIM

Enhanced project visualization, improved scheduling, better cost management, and reduced risks are key benefits of 4D/5D BIM (Smith et al., 2020; Johnson & Lee, 2019).

Empirical studies show that 4D BIM reduces scheduling errors by 35% and delays by 25%, while 5D BIM improves cost estimation accuracy by 20% and reduces budget overruns by 15% (Babič et al., 2010; Monteiro & Martins, 2013).

7. Challenges of 4D/5D BIM Implementation

High initial costs, lack of skilled workforce, interoperability issues, and resistance to change are significant barriers to adoption (Ghaffarianhoseini et al., 2017; Hartmann et al., 2012).

The absence of standardized workflows and guidelines further complicates implementation (Cao et al., 2015)

2.10.2 Research Gap

Based on the objectives and scope of the study, the following research gaps have been identified:

1. Limited Application of 4D/5D BIM in Ethiopia

While BIM adoption is growing in Ethiopia, the use of 4D (time) and 5D (cost) BIM remains limited. Most studies focus on 3D BIM for design and visualization, with minimal emphasis on its application in scheduling and cost management.

There is a lack of empirical evidence on the specific benefits and challenges of implementing 4D/5D BIM in Ethiopian construction projects.

2. Lack of Case Studies in the Ethiopian Context

Existing studies on BIM adoption in Ethiopia are general and do not provide detailed insights into specific projects or sectors. The selected building case study projects offer a unique opportunity to analyze the practical application of 4D/5D BIM in a real-world context.

3. Insufficient Focus on Implementation Challenges

While challenges such as high costs and lack of expertise are acknowledged, there is limited research on strategies to overcome these barriers in Ethiopia. The study aims to address this gap by identifying lessons learned and providing recommendations for successful implementation.

4. Lack of Integration Between Time and Cost Dimensions

Current practices in Ethiopia do not fully leverage the integration of time (4D) and cost (5D) dimensions in BIM. This study aims to explore how these dimensions can be effectively combined to improve project outcomes.

The literature review highlights the potential of 4D/5D BIM to address the challenges faced by the Ethiopian construction industry, such as delays, cost overruns, and poor coordination. However, significant gaps remain in understanding its application, benefits, and challenges in the Ethiopian context. This study aims to bridge these gaps by focusing on the New Ethiopian National Theatre project, providing practical insights and recommendations for the successful implementation of 4D/5D BIM in Ethiopia.

3 RESEARCH METHODOLOGY

3.1 Research Design and Approach

This chapter provides a comprehensive explanation of the research methodology employed in this study. It includes the research design, data collection techniques, study approach, data analysis methods, validity and reliability measures, ethical considerations, and additional methodologies to strengthen the rigor and depth of the research. The methodology is tailored to address the research objectives and provide a robust framework for understanding the application of 4D/5D BIM in the construction project management of selected building projects in Addis Ababa.

3.1.1 Research Philosophy

The research philosophy underpinning this study adopts a pragmatic approach, which emphasizes the practical application of knowledge in real-world scenarios (Creswell, 2014). This philosophy aligns with the mixed-method research design that combines both qualitative and quantitative methodologies to provide a comprehensive understanding of the implementation of 4D/5D BIM in the context of selected building projects in Addis Ababa.

The Research Philosophy Matrix outlines the key aspects of this philosophy:

Table 3-1 Research Philosophy Matrix

Aspect	**Description**	**Application to Study**
Philosophical study	Pragmatic Reality	Focused on understanding the real-world implications of BIM implementation.
Nature of the study	Observable Phenomena	Emphasizes direct observation and measurement of BIM outcomes.
Methodology	Mixed Method	Integrates qualitative insights with quantitative data for a robust analysis.
Strategy	Selected Building projects in Addis Ababa	In-depth exploration of the selected building projects.

3.2 Data Collection Methodology

3.2.1 Case Studies

Given that comprehensive BIM implementation, particularly incorporating 4D and 5D, is still in its early stages within the industry, this research focuses on case studies of two companies involved in three projects that currently utilize BIM at least at the 3D level; the implementation and analysis of 4D/5D BIM workflows for these projects is undertaken as part of this research.

3.2.1 Primary Data Collection Methods

The primary data collection methods utilized in this research include:

Table 3-2 Primary Data Collection Method and Strategies

Method	Description	Implementation Strategy	Expected Outcome
Direct Observation	Conducting site visits and monitoring BIM processes	Utilizing structured observation sheets and progress tracking forms	Gathering first-hand implementation data and identifying challenges.
Document Analysis	Reviewing project documentation and BIM plans	Employing a systematic coding framework for data extraction	Compiling historical data and identifying implementation patterns.
Expert Interviews	Engaging with project stakeholders and BIM managers	Conducting semi-structured interviews and write out sessions	Gaining insights into implementation challenges and success factors.

3.1.1.1 Semi-Structured Interviews

Semi-structured interviews are conducted with the Project BIM Manager. The interviews are designed to explore participants' experiences, perceptions, and insights regarding the implementation of 4D/5D BIM. Open-ended questions allow for flexibility and encourage participants to share detailed responses (Kvale & Brinkmann, 2015).

3.1.1.2 Focus Group Discussions

Focus group discussions are organized with a diverse group of stakeholders to facilitate collaborative discussions about the benefits, challenges, and overall impact of 4D/5D BIM. This technique provides a platform for participants to share their perspectives and engage in dialogue, generating rich data through group interactions (Morgan, 1997).

3.1.1.3 Secondary Data Collection

In addition to primary data collection, secondary data is reviewed to provide context and support for the findings. This review ensures that the study is grounded in existing knowledge and provides a comprehensive understanding of the research topic. Secondary data collection is conducted through various sources:

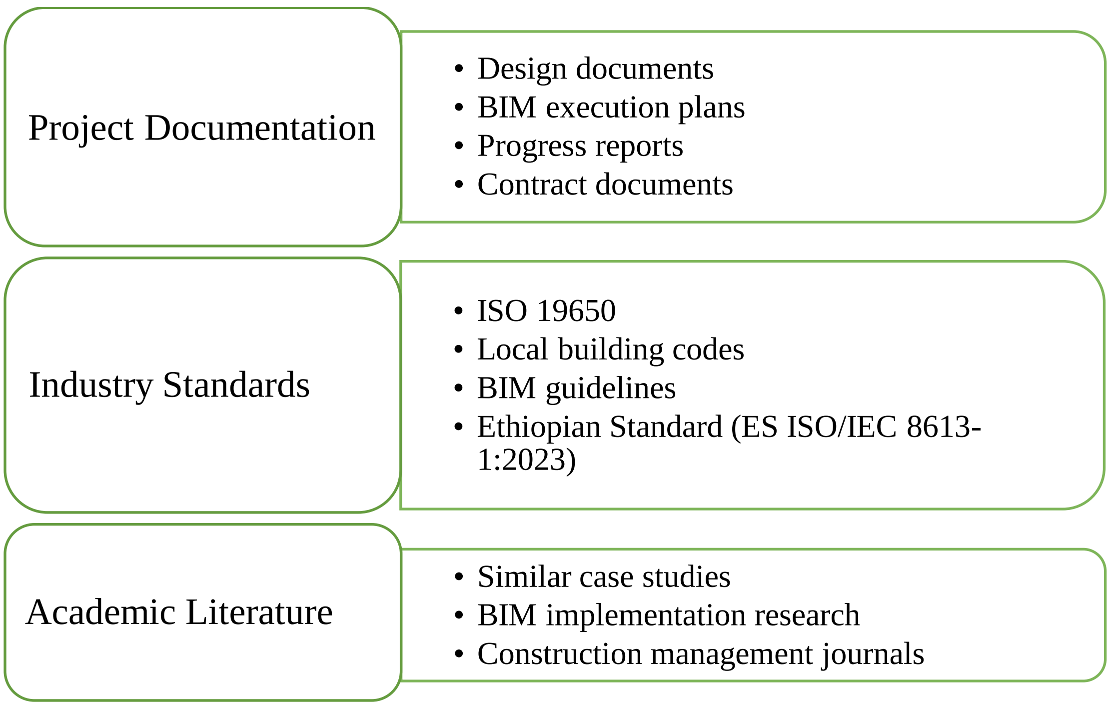


Figure 11 Secondary Data Collection Sources

These secondary sources provide valuable context and background information that supports the primary data findings, ensuring a well-rounded analysis (Bryman, 2016).

3.3 Data Analysis Framework

3.3.1 Qualitative Analysis Approach

The data collected through document analysis, on-site observations, interviews, and focus group discussions is analyzed using a combination of qualitative and quantitative methods:

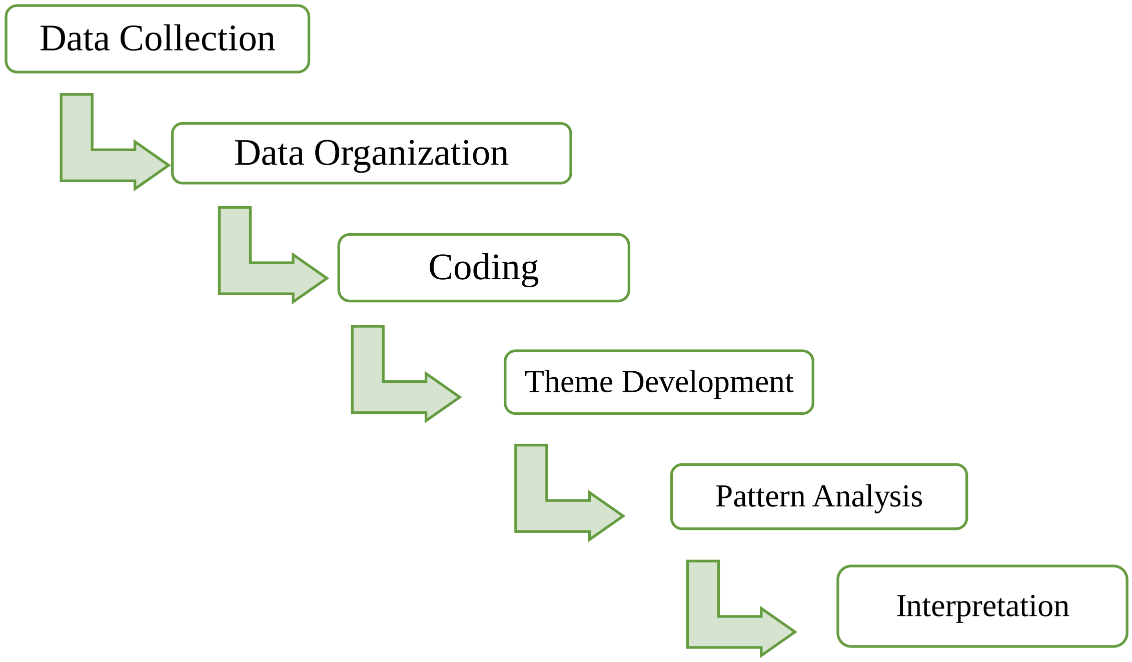


Figure 12 Qualitative Analysis Approach

This framework facilitates the identification of themes and patterns within the qualitative data, enhancing the overall understanding of BIM implementation.

3.3.2 Analysis Methods Matrix

The analysis methods employed in this research include:

Table 3-3 Analysis Methods Matrix

Analysis Type	**Tools/Techniques**	**Purpose**	**Output**
Thematic Analysis		Identify key themes and extract implementation patterns	Thematic insights and categorization of challenges.
Process Analysis	Flow diagrams	Evaluate workflows and identify bottlenecks	Visual process maps and efficiency data.
Impact Assessment	Performance metrics	Measure BIM benefits and quantify improvements	Impact metrics and value propositions.

3.1.1.4 Quantitative Analysis

Where applicable, quantitative data from project schedules, cost management records, and progress reports is analyzed using descriptive statistics. This analysis provides numerical insights into the efficiency, cost savings, and time management benefits of 4D/5D BIM.

3.4 Research Quality Assurance

3.4.1 Validity Framework

Ensuring the validity of the research findings is crucial. The validity framework includes:

Table 3-4 Validity framework

Type	**Strategy**	**Implementation Method**
Internal Validity	Data triangulation, member checking, peer review	Cross-verification of multiple data sources and stakeholder validation on the case study projects.
External Validity	Thick description, context documentation	Detailed context analysis and applicability assessment.
Construct Validity	Multiple evidence sources, chain of evidence	Systematic data collection and expert validation processes.

3.4.2 Reliability Measures

The reliability of the research is maintained through:

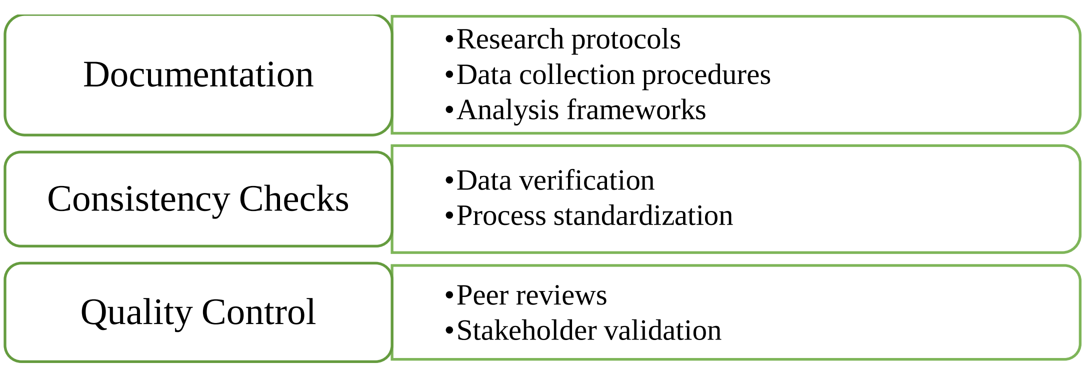


Figure 13 Reliability Measures

Implementing these measures ensures that the research findings are replicable and trustworthy (Mason, 2018).

3.4.3 Ethical Considerations

Ethical considerations are integral to the research process. The following aspects are addressed:

Table 3-5 Ethical Considerations

Aspect	Requirements	Implementation
Consent	Informed consent, voluntary participation	Use of consent forms and information sheets
Confidentiality	Data protection, privacy measures	Implementation of data encryption and anonymous reporting
Professional Ethics	Research integrity, unbiased reporting	Adherence to ethical guidelines and transparent documentation

These ethical measures ensure the protection of participants and the integrity of the research (Bourne, 2015).

4 4D/5D FRAMEWORK as Per ISO 19650 and Ethiopian Standard (ES ISO/IEC)

Introduction

The primary objective of this framework is to integrate BIM processes with ISO standards to streamline and enhance project management efficiency across the construction project management lifecycle. By aligning BIM methodologies with internationally recognized ISO standards (such as ISO 19650), this framework aims to:

Key Purposes

Table 4-1 Key Purpose of the Framework

Purpose	Description
Integration	Seamless merger of time schedules and cost data with 3D BIM models
Standardization	Unified approach to project timeline and cost management
Optimization	Enhanced decision-making through visual simulation and cost analysis
Efficiency	Reduced errors through automated quantity takeoffs and schedule coordination
Compliance	Alignment with global standards and best practices

Framework scope

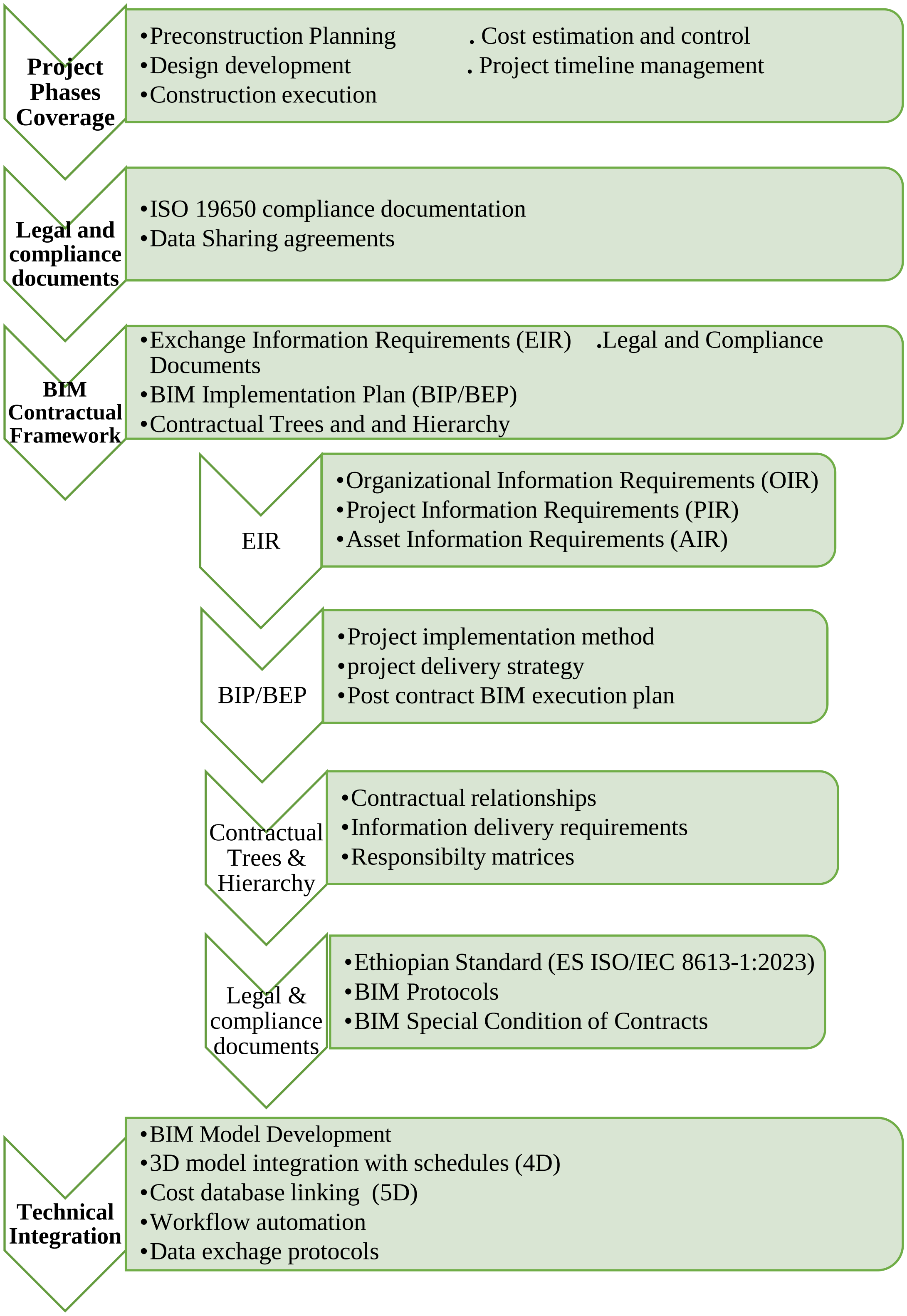


Figure 14 Framework Scope

Framework Applicability

Project Types

This framework can be applicable in a variety of project types, including building construction, commercial developments, and residential complexes. Additionally, it is suited for industrial facilities and institutional buildings, as well as infrastructure projects such as transportation systems and utility networks. The framework can also be effectively utilized in public facilities and urban developments, demonstrating its versatility and comprehensive nature across multiple sectors of construction and development.

Implementation Levels

Stakeholders can implement BIM according to their project's complexity and needs. Starting from basic, moving to intermediate, and finally advancing to advanced where full 4D/5D integration is implemented for comprehensive project management.

Table 4-2 Framework Implementation Level

Level	**Description**	**Suitable For**
Basic	Simple 4D scheduling	Small projects
Intermediate	4D+basic cost integration	Medium projects
Advanced	Full 4D/5D integration	Large complex projects

4.1 Work flow as per ISO 19650 as Building information management

To ensure a structured and effective implementation of Building Information Modelling (BIM), the Exchange Information Requirements (EIR) must be developed in alignment with foundational documents such as the Organizational Information Requirements (OIR), Asset Information Requirements (AIR), Project Information Requirements (PIR), and Strategic Information Requirements (SIR). These documents collectively inform the scope, depth, and purpose of information exchange across the project lifecycle.

According to the Ethiopian Standard **ES 7030:2023**, the EIR must address three core domains: **Information Management**, **Technical**, and **Commercial**. Each domain outlines specific requirements that guide the delivery team in aligning their BIM Implementation Plan (BIM IP) with the project’s strategic and operational goals.

The **Information Management** section includes standards and classification systems, role definitions, planning protocols, BIM uses, cybersecurity, spatial coordination, collaboration processes, Common Data Environment (CDE) implementation, system performance monitoring, compliance auditing, asset information delivery strategies, training needs, and health and safety considerations.

The **Technical** section specifies software platforms, data exchange formats, coordinate systems, levels of detail, and model scope definitions. Meanwhile, the **Commercial** section outlines acceptance criteria, project milestones, client objectives, responsibility matrices, and BIM capability assessments. The BIM IP must respond directly to these requirements using a question-and-answer format to ensure clarity and traceability.

Figure 15 illustrates a structured workflow developed in alignment with ISO 19650 and Ethiopian Standard ES 7030-7031**,** providing a visual framework for managing information across a BIM-enabled project lifecycle. It maps out the sequential phases from project initiation to close-out, showing how standardized information exchanges, responsibilities, and deliverables are coordinated through key BIM documents. This diagram functions as a strategic overview of the collaborative process, ensuring compliance, consistency, and traceability throughout the project timeline.

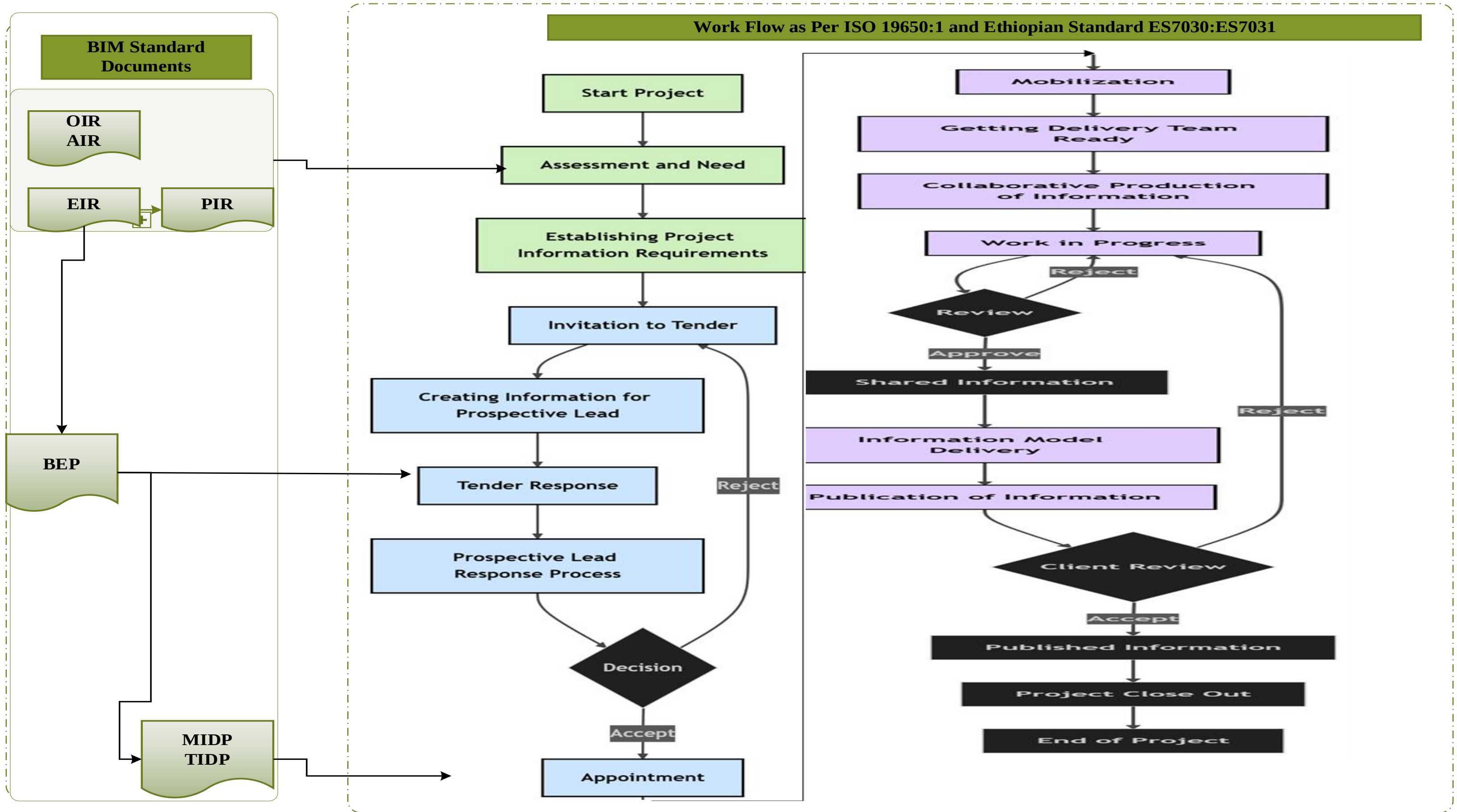


Figure 15 BIM Information Management Workflow (Developed Aligned with ISO 19650 and ES 7030-7031 Standards)

4.1.1 Technical Integration

4.1.1.1 Selecting BIM Software for 4D/5D BIM

Selecting the right BIM software for 4D (time scheduling) and 5D (cost estimation) is a critical decision for project teams. The software should align with the project's requirements, facilitate collaboration, ensure data accuracy, and integrate seamlessly with other systems. Below are the key criteria to consider when selecting BIM software for 4D/5D workflows.

The BEXEL Manager has been selected for this process as it meets the criteria, particularly because it offers a one-year free educational license to legitimate university students.

4.1.1.2 Creating a Project and Managing Model Data in BEXEL Manager

In BEXEL Manager, projects can be initiated by federating several BX3 files or IFC files. This process, known as the BIM model federation process, consolidates multiple model sources into a unified project model for further analysis and management.

General Project Information

When opening a BIM model for the first time, it is essential to understand the basic statistics of the project, such as:

- The number of data sources included in the model.
- The total count of elements, categories, and families.

This information provides an overview of the model's scope and complexity, which is critical for planning subsequent workflows.

4.1.1.3 Model Data Management

Model data management in BEXEL Manager enables users to visually inspect, validate, and enhance the quality of the BIM model. Below is an outline of the key steps involved in managing the model data effectively.

4.1.1.4 Initial Model Review

When a model is first imported into BEXEL Manager, the initial step is to conduct a quick review to assess its overall quality and compliance with project standards. The purpose of this review is to identify any issues early in the workflow. Key aspects examined during this stage include:

Model Sources:

How many data sources are included in the model?

- Are the sources properly consolidated?

Model Organization:

- Number of categories, families, and elements in the model.
- Verification of family names to ensure they align with the BIM Execution Plan (BEP).

Model Accuracy:

- Are elements modeled according to their family definitions?
- Are elements correctly placed at the appropriate levels?

Visual Inspection:

- A general visual review to identify inaccuracies in the geometry or placement of elements.

Level of Detail (LOD):

- Assess whether the model elements comply with the LOD requirements specified in the BEP.

Material Properties:

- Are materials and their characteristics modeled in accordance with the standards outlined in the BEP?

The findings from this initial review are compiled into a report, which can be shared with the model author (typically the designer) for corrections or further refinement.

4.1.1.5 Automated Data Validation Process

BEXEL Manager offers advanced automated data validation capabilities, allowing users to inspect and manage BIM data efficiently. The validation process is streamlined using Add-ins for Information Delivery Specification (IDS) verification based on predefined rules. This ensures that all BIM elements meet the mandatory property requirements for each project stage.

Key features of the automated validation process include:

Property Compliance Checks:

- Verification of element properties against project-specific requirements or international standards.
- Example checks include mandatory attributes like dimensions, material specifications, and classification codes.

Issue Reporting:

- Any detected issues are flagged and reported.
- Reports can be shared with responsible project participants to resolve identified problems.

BCF Integration:

- Created issues are saved as BCF (BIM Collaboration Format) files, which can be exported and shared.
- Users can utilize platforms such as BIM Collab to directly share these issues online, enabling seamless collaboration across the project team.

This automated validation process ensures that the model complies with project standards and that all stakeholders are informed of required corrections. **Figure 16** illustrates an automated BIM data validation workflow, beginning with multiple discipline-specific IFC files Architectural (AR), Structural (ST), and Mechanical, Electrical, and Plumbing (MEP). These are merged into a federated model**,** which is then analyzed using a data validation add-in powered by a knowledge base, COBie, and a customized checklist. The tool generates automatic selection sets and validation results, culminating in a comprehensive data validation report. This report feeds into broader project insights such as KPIs, dashboards, benchmarking, and AI/ML analytics—and facilitates seamless information exchange among stakeholders**.** It emphasizes efficiency, accuracy, and smart decision-making in BIM-enabled environments.

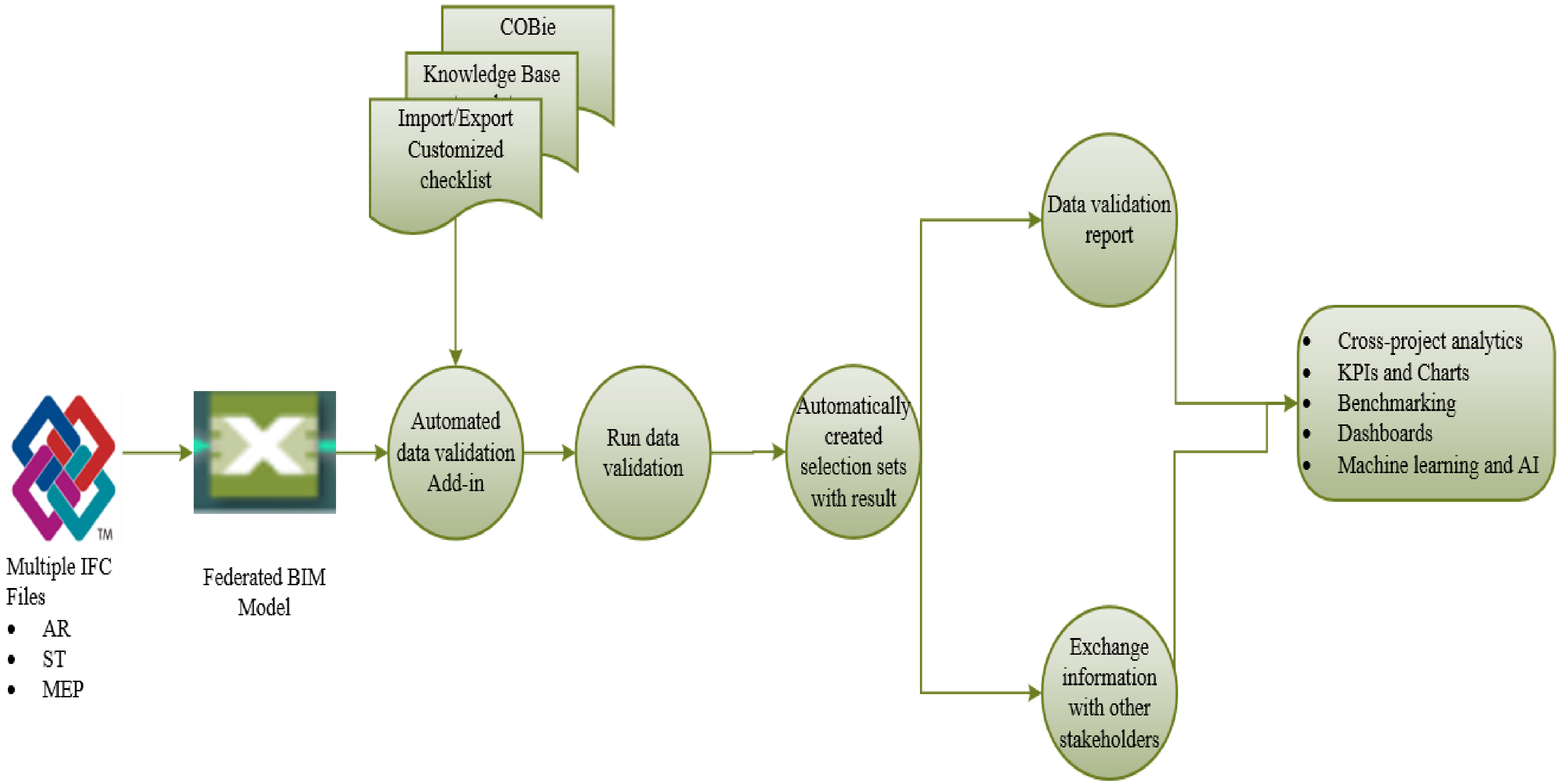


Figure 16 Automated Data Validation Framework (Own Developed based on ISO19650 and Bexel Workflow

4.1.1.6 Automated Model Data Enrichment

Once data validation is complete and missing properties are identified, the next step is model data enrichment. This process i
nvolves adding or updating missing information in the BIM model using the BEXEL Manager Data Enrichment Add-In. The steps include:

Property Synchronization:

- Missing properties can be synchronized between Autodesk® Revit® and BEXEL Manager.

This allows stakeholders who do not directly interact with the BIM model to manage the data using Excel files.

Data Editing and Import/Export:

- Properties and data edited or created in BEXEL Manager can be exported to an Excel file for external editing.
- Once modified, the data can be imported back into Revit, with updates automatically applied to the BIM model.

Creation of New Properties:

- If new properties are created in BEXEL Manager, these can be imported into Revit as native metadata.

The data enrichment process allows teams to manage and update properties collaboratively, reducing bottlenecks and ensuring that all necessary information is incorporated into the model.

4.1.1.7 Model Data Validation Workflow

The combined steps of review, validation, and enrichment form a robust model data validation workflow in BEXEL Manager. The workflow ensures that:

1. The model is reviewed for accuracy, completeness, and compliance with the BIM Execution Plan (BEP).
2. Automated checks are performed to validate the data against project standards and information delivery specifications.
3. Missing data is enriched and synchronized between BEXEL Manager, Revit, and external tools (e.g., Excel), ensuring the model is comprehensive and up-to-date.

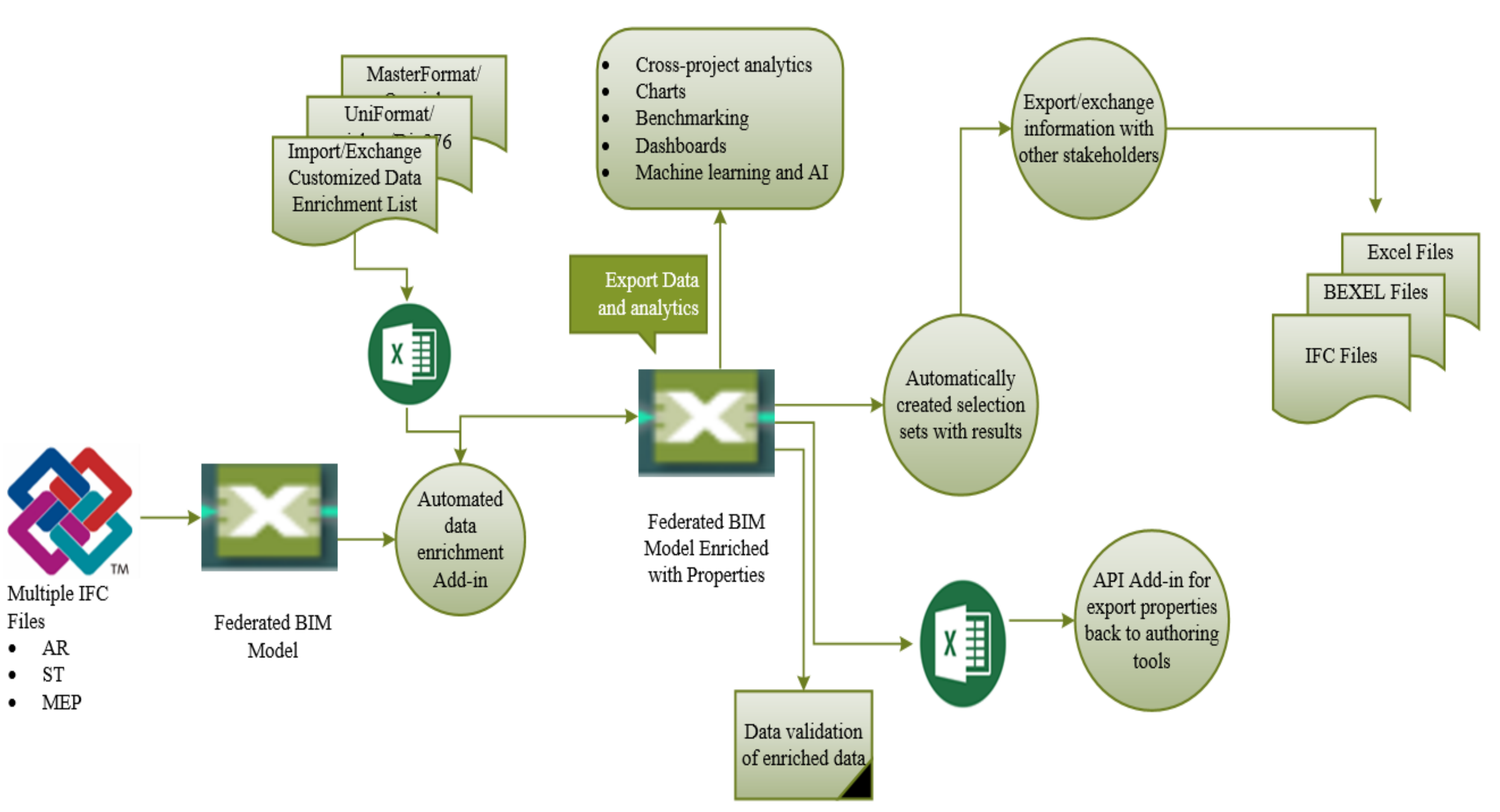


Figure 17 Automated Model Data Enrichment Framework (Own Developed based on ISO19650 and Bexel Workflow)

Figure 17 presents a data enrichment and export workflow built around a federated BIM model. It visualizes how discipline-specific IFC files (Architecture, Structure, MEP) are combined and enriched through an automated process. The enriched model is then validated and exported in various formats such as Excel, BEXEL, and IFC for downstream uses including stakeholder collaboration, dashboards, benchmarking, and AI/ML analytics. The workflow demonstrates how streamlined integration and smart validation tools support informed decision-making across the BIM lifecycle.

4.1.1.8 Clash Detection Framework for BIM Projects

Clash detection is a critical part of Building Information Modeling (BIM) workflows, aimed at identifying and resolving geometric conflicts between elements within a model. The Clash Detection Module in BEXEL Manager enables project teams to perform comprehensive conflict analysis across multiple groups of elements, ensuring smoother project execution by reducing quality issues, avoiding delays, and minimizing additional costs. This framework outlines the clash detection process, types, and workflow, providing a systematic approach for incorporating clash detection into BIM-based projects.

Importance of Clash Detection in BIM Workflows

Clash detection is vital for ensuring the constructability of a project and avoiding costly errors during the construction phase. Conflicts often arise between Mechanical, Electrical, and Plumbing (MEP) systems or between architectural, structural, and MEP components due to their complexity. Identifying and resolving these clashes at the design stage minimizes risks, improves quality, and prevents construction delays.

- Ensuring proper placement of complex linear systems (e.g., MEP systems) within the building structure.
- Identifying duplicates caused by multiple authoring tools or model sources.
- Detecting conflicts that could disrupt on-site construction workflows.
- Simplifying large clash detection lists for better management and resolution.

Clash Detection Process

The clash detection process in BEXEL Manager involves several steps to prepare and analyze the model for conflicts. These steps ensure that clash detection aligns with the needs of stakeholders and project stages:

1. **Import Clash Detection Matrix and Rules**:
    - Define and import a clash detection matrix and rules to apply appropriate checks based on project requirements.
    - Ensure that the model is prepared for accurate and efficient clash detection.
2. **Check for Duplicates:**
    - Identify duplicate elements caused by different authoring tools or model sources.
    - Use the duplicate detection option to eliminate redundancy and avoid false clashes.
3. **Simplify Clash Detection Lists:**
    - Consolidate and categorize large numbers of clashes to prioritize resolution.
    - Focus on high-priority clashes that could impact construction schedules or quality.
4. **Locate Clashes on Floor Plans:**
    - Use floor plan views to pinpoint clashes and analyze collision density in specific areas, such as individual floors.
    - This helps prioritize areas with the highest conflict density.
5. **Analyze Main Conflicts:**
    - Identify the most critical conflicts in the clash detection job.
    - Focus on resolving clashes that could disrupt project execution in the short term.
6. **Assess Construction Impacts:**
    - Determine whether any unresolved clashes could delay or stop on-site works in the upcoming period.
    - Collaborate with stakeholders to address these conflicts before construction begins.

Figure 18 presents a discipline-based clash detection matrix used in BIM coordination. It systematically identifies potential spatial conflicts such as hard clashes and required clearances between building elements across various disciplines, including Architecture, Structure, HVAC, Plumbing, Drainage, Fire-Fighting, and Electrical.

		Architecture												Structure						HVAC				Plumbing		Drainage		Fire-Fighting			Electrical								
	Components	Ceilings	Curtain Panels	Curtain wall mullions	Doors	Floors	Railings	Ramps	Roofs	Speciality Equipment	Stairs	Walls	Windows	Columns	Foundations	Floors	Framing	Trusses	Walls	Air Terminals	Ducts/Acce/Fittings	Mechanical Equipment	Pipes & fittings	Pipes & fittings	Plumbing Fixtures	Pipes & fittings	Drainage Fixtures	Mechanical Equipment	Pipes & fittings	Sprinklers	Cable Trays & fittings	Communication Devices	Data Devices	Electrical Equipment	Electrical Fixtures	Fire Alarm Devices	Lighting Devices	Lighting Fixtures	Security Devices
Architecture	Ceilings																																						
	Curtain Panels	H																																					
	Curtain wall mullions	H	N/A																																				
	Doors	N/A	H	N/A																																			
	Floors	N/A	N/A	N/A	H																																		
	Railings	N/A	N/A	N/A	H	N/A																																	
	Ramps	N/A	N/A	N/A	H	N/A	N/A																																
	Roofs	N/A	H	H	H	N/A	N/A	N/A																															
	Speciality Equipment	H	H	H	H	H	H	H	N/A																														
	Stairs	N/A	H	H	N/A	N/A	N/A	N/A	N/A	H																													
	Walls	N/A	N/A	H	N/A	N/A	N/A	N/A	H	H	H																												
	Windows	N/A	N/A	N/A	N/A	H	H	H	H	H	H	N/A																											
Structure	Columns	N/A	H	H	H	N/A	H	H	N/A	H	H	N/A	H																										
	Foundations	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A																									
	Floors	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A																								
	Framing	H	H	H	H	N/A	N/A	H	N/A	H	H	H	N/A	N/A	N/A	H																							
	Trusses	H	H	H	H	N/A	N/A	H	N/A	H	H	H	N/A	N/A	N/A	H	H																						
	Walls	N/A	H	H	H	H	H	H	H	H	H	H	H	N/A	N/A	N/A	H	H																					
HVAC	Air Terminals	N/A	H	H	H	N/A	N/A	N/A	N/A	H	H	H	H	H	N/A	N/A	H	H	H																				
	Ducts/Acce/Fittings	C-50	H	H	H	H	N/A	N/A	H	H	H	C-50	H	C-50	N/A	H	H	C-50	C-50	H																			
	Mechanical Equipment	C-50	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C-50																		
	Pipes & fittings	C-50	H	H	H	N/A	N/A	N/A	C-50	H	H	C-50	H	H	N/A	N/A	H	H	C-50	C-50	C-50	C-50																	
Plumbing	Pipes & fittings	C-50	H	H	H	N/A	N/A	N/A	C-50	H	H	C-50	H	H	N/A	N/A	H	H	H	C-50	C-50	C-50	C-150																
	Plumbing Fixtures	N/A	H	H	H	N/A	N/A	N/A	N/A	H	N/A	H	H	H	N/A	N/A	H	H	H	N/A	N/A	N/A	N/A	N/A															
Drainage	Pipes & fittings	C-50	H	H	H	H	H	N/A	H	H	H	C-50	H	H	H	N/A	H	H	H	C-50	C-50	C-50	C-150	C-150	H														
	Drainage Fixtures	N/A	H	H	H	H	H	H	H	H	H	H	H	H	H	N/A	H	H	H	N/A	H	N/A	H	H	H	H													
Fire-Fighting	Mechanical Equipment	C-50	H	H	H	N/A	N/A	N/A	H	H	H	H	H	H	H	H	H	H	H	H	C-50	H	C-50	H	C-25	H	H												
	Pipes & fittings	C-50	H	H	H	N/A	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C-50	H	C-150	C-150	H	C-150	H	C-50											
	Sprinklers	N/A	H	H	H	N/A	N/A	N/A	N/A	H	H	H	N/A	H	H	H	H	H	H	H	C-50	H	C-50	C-50	N/A	H	N/A	N/A	N/A										
Electrical	Cable Trays & fittings	C-50	H	H	N/A	N/A	N/A	N/A	N/A	H	H	H	N/A	H	N/A	H	H	H	H	H	C-300	H	C-300	C-300	N/A	C-300	N/A	C-50	C-300	H									
	Communication Device	N/A	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A								
	Data Devices	N/A	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A							
	Electrical Equipment	N/A	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	H	N/A	N/A	N/A	C-300	C-50	C-100	C-100	N/A	C-100	N/A	C-50	C-100	H	H	H	H						
	Electrical Fixtures	N/A	H	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	N/A	H					
	Fire Alarm Devices	N/A	H	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	H	N/A	N/A	C-100	H	H	C-100	C-100	N/A	C-100	N/A	N/A	C-100	H	H	N/A	N/A	H	H				
	Lighting Devices	N/A	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	H	H	C-50	H	H	N/A	H	N/A	C-50	H	H	H	N/A	N/A	H	N/A	H			
	Lighting Fixtures	N/A	H	H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H	N/A	N/A	H	N/A	N/A	H	H	C-50	H	H	N/A	H	N/A	C-50	H	H	H	N/A	N/A	H	N/A	H	H		
	Security Devices	N/A	H	H	H	N/A	N/A	N/A	N/A	H	N/A	H	N/A	H	N/A	N/A	H	N/A	H	H	H	C-50	H	H	N/A	H	N/A	C-50	H	H	H	N/A	N/A	H	N/A	H	H	H	

Key	
H	Hard clash - Where two components are in confilict with each
C	Clearance reuired. Clearance value in mm indicated next to C.
N/A	Not Applicable.

Figure 18 Clash Matrix Example

Types of Clash Detection

BEXEL Manager supports various clash detection types, each tailored to specific conflict scenarios. These types help identify and resolve different kinds of issues within BIM models:

Hard Clash

- Detects cases where elements physically intersect or pass through one another.
- Example: A duct passing through a structural beam.

Hard Clash – Conservative

- Similar to the Hard Clash but includes a conservative intersection method for more precise clash detection.
- This method applies stricter criteria to identify potential clashes with higher accuracy.

Clearance Clash (Soft Clash)

- Detects conflicts where an element encroaches on the buffer zone or clearance space around another element.
- Commonly used for identifying issues related to maintenance access or safety clearances

Duplicate (Bounds)

- Checks for duplicate elements within the model.
- Duplicates often occur when sub-models from various sources are combined, leading to redundant elements that may cause false clashes.

Containment Clash

- Finds elements located within a container element, such as rooms or spaces.
- Example: Ensuring that all furniture and fixtures are within the defined boundaries of a room.

Clash Detection Workflow

The clash detection workflow in BEXEL Manager provides a structured process for identifying, analyzing, and resolving conflicts. The workflow can be integrated into the overall BIM coordination process to ensure smoother project delivery.

Model Preparation:

- Import the BIM model into BEXEL Manager and ensure it is federated with all necessary sub-models (e.g., architectural, structural, MEP).
- Define clash detection rules and matrices based on project requirements.

Initial Clash Detection:

- Perform an initial run of clash detection to identify potential conflicts.
- Categorize clashes by type (e.g., hard clashes, soft clashes, duplicates).

Clash Prioritization:

- Simplify the clash detection list by grouping similar clashes or focusing on high-priority issues.
- Use visual tools, such as floor plans, to analyze collision density and pinpoint critical areas.

Issue Reporting:

- Generate detailed reports of detected clashes, including their type, location, and severity.
- Share reports with relevant stakeholders, such as designers or contractors, for resolution.

Conflict Resolution:

- Collaborate with stakeholders to resolve identified clashes.
- Update the BIM model to reflect changes and ensure that resolved clashes are no longer present.

Final Validation:

- Perform a final clash detection check to confirm that all critical conflicts have been resolved.
- Ensure that the model is clash-free and ready for construction.

Figure 19 depicts a comprehensive clash detection and data enrichment workflow in a BIM environment. It begins with the integration of multiple discipline-specific IFC files—Architecture, Structure, and MEP into a federated BIM model. From there, predefined clash rules are applied to identify various clash types, including hard clashes, clearance issues, and duplicate elements.

Through an automated process, IFC relationships are added, enriching the dataset based on the clash results. These are then exported into diverse outputs such as KPIs, custom reports, dashboards, schedule simulations, and collaborative BIM platforms. The flowchart underscores a systematic and intelligent clash analysis process that enhances data quality, supports better decision-making, and streamlines coordination across project stakeholders.

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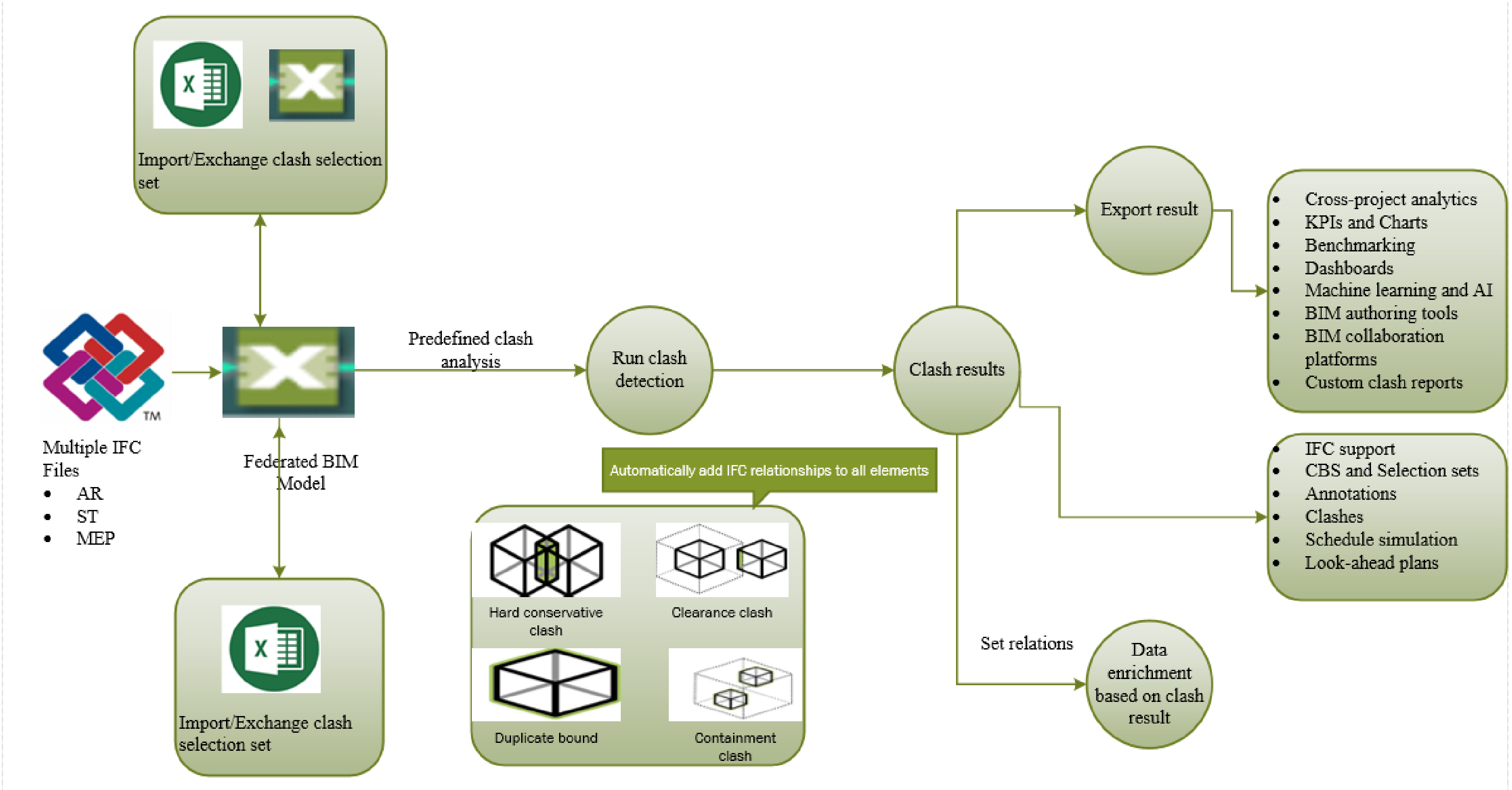

Figure 19 Clash Detection Framework (Own Developed based on ISO19650 and Bexel Workflow)

4.1.1.9 Automated Quantity Takeoff Generation

Quantity Takeoff Framework for BIM Projects

The Quantity Takeoff (QTO) module in BEXEL Manager is a powerful tool that enables users to calculate quantities directly from the geometry of 3D BIM models. This capability is crucial for accurate cost estimation, construction planning, and change management. The following framework outlines the steps, workflows, and advanced features for implementing QTO in BIM projects.

Creating a Quantity Takeoff Breakdown Structure

A Quantity Takeoff Breakdown Structure (QTO-BS) is a hierarchical organization of BIM elements grouped based on predefined or custom rules. This structure is essential for categorizing model components and extracting quantities efficiently.

Steps to Create a Quantity Takeoff Breakdown Structure:

1. **Creating a Blank Quantity Takeoff**

Use the Add Breakdown Rule command to group BIM elements by predefined rules such as:

- Building, Building Level
- Category, Family
- Source, System Name
- Material

Alternatively, create custom rules using properties like:

- Selection Sets
- Property Range
- Containing Material

2. **Creating Quantity Takeoff from Selected Elements:**
   - Select elements from the appropriate category or family in the structure.
   - Isolate selected elements in the Perspective View for further analysis.
   - This approach is particularly useful for change management, as it allows users to focus on specific changes in the model.

Color-Coded Quantity Takeoff Breakdown Structure

Color-coding in QTO provides a visual representation of grouped elements, aiding in better comprehension and communication among stakeholders.

Steps to Apply Color Coding:

- Use the Set Color Coding Rule to assign unique colors to specific quantity takeoff groups.
- View the model in Perspective Color-Coded or Ortho Color-Coded modes.
- This feature enhances visualization and helps identify specific QTO items at a glance.

Quantity Takeoff Reports and Templates

After creating QTO structures, reports can be generated for further analysis and documentation.

Key Features:

Export Reports:

Reports can be exported in XLSX format with options such as:

- Flat Table
- Breakdown Structure
- Styled Report

Template Reusability:

- Quantity takeoff rules can be shared across projects as templates.
- Universal QTO templates can be exported to the Knowledge Base for future use.
- Project-specific QTO templates can be saved as Custom Templates.

Import Predefined Templates:

Users can import QTO templates from the Knowledge Base or custom-created templates, saving time and ensuring consistency.

4.1.1.10 Cost Management Framework for BIM Projects

Cost management in BEXEL Manager is a comprehensive workflow that involves creating, assigning, and managing cost classifications and cost items. The framework is designed to streamline cost estimation and integrate it seamlessly with BIM models.

Cost Classification Workflows

BEXEL Manager provides multiple workflows for creating cost classifications, allowing flexibility based on user preferences, project needs, and available information.

Workflows for Cost Classification:

Manual Creation:

Create a blank cost classification in the Cost Editor and manually populate it by adding classification and cost items.

Excel-Based Creation:

- Use an Excel spreadsheet to define classifications and cost items.
- Import the spreadsheet into BEXEL Manager for integration.

Automatic Creation from CBS (Custom Breakdown Structure):

- Automatically generate cost classifications based on a predefined CBS.
- Adjust the classification as needed within BEXEL Manager.

Automatic Creation from QTO:

- Generate a complete cost classification based on predefined QTO.
- This method automates the process by linking cost items to model elements.

Benefits of Workflow Options:

- Manual workflows facilitate the integration of existing cost databases and coding standards.
- Automated workflows offer high efficiency by reducing manual input and streamlining the process.

Creating a Cost Classification

To add cost information to BIM model elements, a classification system must be established. This can be based on standards like UniFormat or MasterFormat, or customized to suit project-specific needs.

Steps to Create a Classification System:

1. Open the Classification Editor tab.
2. Create a new classification or import an existing one.
3. Populate the classification with:
    - Classification Items: Represent cost structures or breakdown groups.
    - Cost Items: Represent cost elements linked to model components.

Automating Cost Item Creation

Cost items can be created and linked to model elements automatically using predefined QTO or CBS. The Cost Creation Wizard facilitates this process.

Steps for Automated Cost Item Creation:

1. Define the Code and Name of cost items using:
    - QTO/CBS properties.
    - Knowledge Base or Custom Templates.
2. Set Rules of Measurement using:
    - Quantity Takeoff.

- Knowledge Base.
- Custom Templates.

3. Export the cost classification to Excel for further adjustments, such as:
    - Unit prices.
    - Quantity formulas.
4. Import the updated Excel file back into BEXEL Manager to finalize the classification.

Linking Cost Items to BIM Model Elements

Cost items can be linked to BIM model elements using the Auto-Assign command or manual linking.

Auto-Assign Workflow:

- Define Element Queries to establish rules for linking cost items to model elements.
- Use the Auto-Assign command to automatically apply cost items to corresponding elements.

Manual Linking Workflow:

- Select specific elements in the model.
- Assign cost items manually for greater control over the process.

4.1.1.11 Resource Management

Resources are essential for cost estimation and construction planning. They include materials, labor, and equipment required for specific tasks.

Steps for Resource Creation:

1. **In BEXEL Manager:**
    - Create a new resource or use an existing one.
    - Define properties such as resource type (Material, Labor, and Equipment), quantity type, unit, and unit cost.
2. **In Excel:**
    - Use a formatted spreadsheet to define and modify resource properties.
    - Import the updated file into BEXEL Manager.

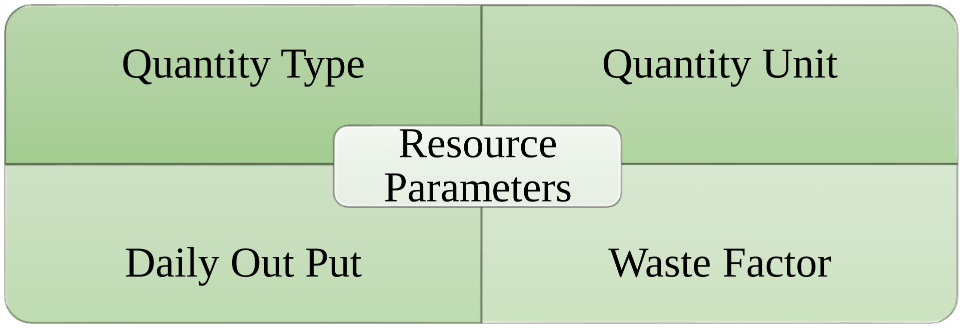

Figure 20 Resource Parameters for Cost Estimation

Cost Estimate Palette

The Cost Estimate Palette is a comprehensive tool for analyzing cost data. It serves as a Bill of Quantities (BOQ) and displays detailed information, including:

- Quantities and units.
- Unit costs (material, labor, equipment).
- Total costs (including tax, subcontractor costs, etc.).

Non-BIM Cost Items

In some cases, cost items may not be linked to BIM model elements (e.g., site surveys). These items can still be included in the cost classification and cost assignment processes.

Figure 21 presents a streamlined smart cost management workflow using BIM. It traces the process from importing IFC files and applying classification rules to generating quantity takeoffs and detailed BOQs. The data is then exported for use in dashboards, custom reports, and AI/ML-driven analytics, enabling efficient and intelligent cost control across construction projects.

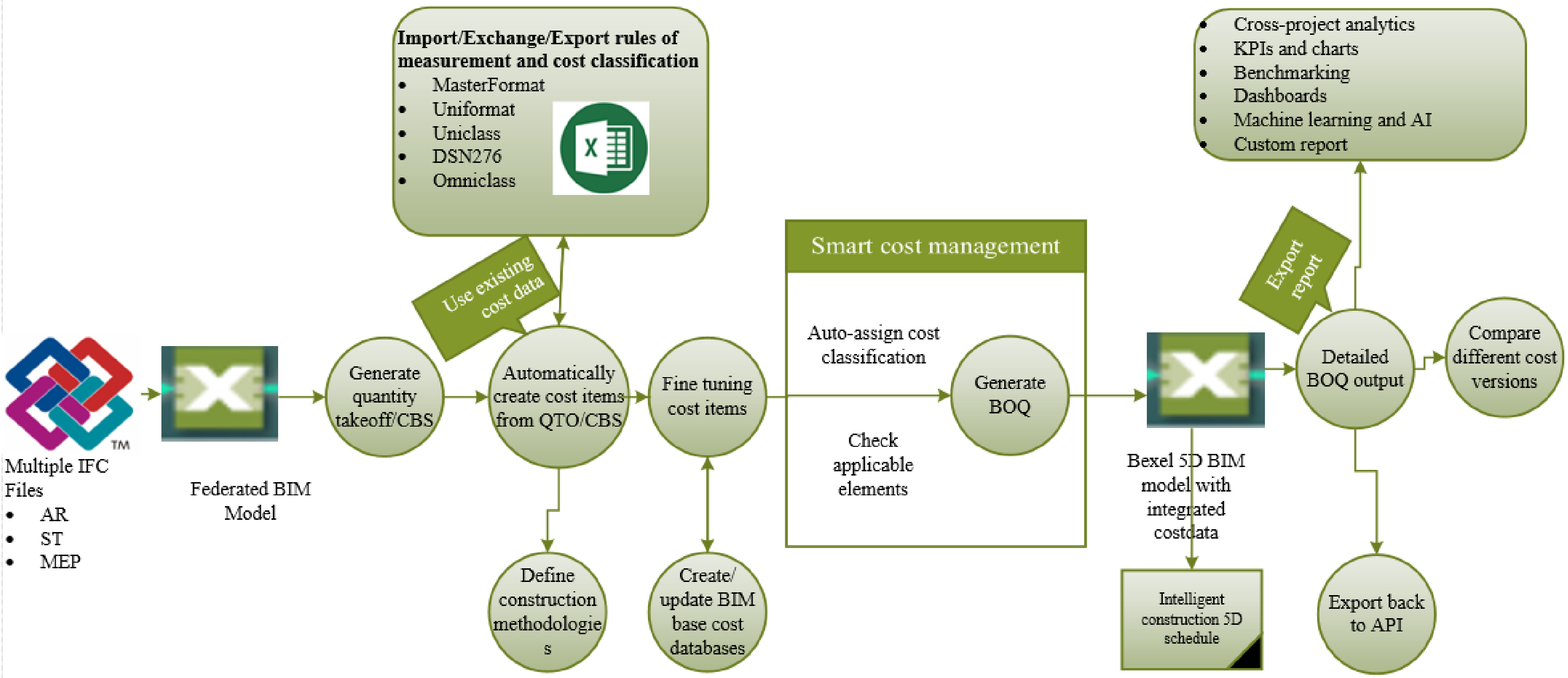

Figure 21 Automated Quantity Takeoff and Cost Management Framework (Own Developed based on ISO19650 and Bexel Workflow)

4.1.1.12 Scheduling Framework for BIM Projects

The Scheduling Module in BEXEL Manager provides advanced tools and workflows for creating, managing, and optimizing project schedules. This functionality supports the development of comprehensive 4D models and 4D/5D animations, enabling planners to link time and cost data with construction activities. The following framework outlines the scheduling principles, workflows, and optimization strategies, forming a structured approach to scheduling in BIM-based construction projects.

Schedule Editor Palette

The Schedule Editor Palette in BEXEL Manager is a central tool for managing existing schedules, creating new schedules, and linking them to BIM models. The schedule consists of hierarchical activities organized across three levels:

- **Parent Task**: Represents an activity containing multiple sub-activities.
- **Children Task**: A sub-activity under a parent task.
- **Leaf Task**: The lowest level activity that does not contain any further sub-activities.

Schedule Display Types

The scheduling module supports multiple display formats to visualize and manage activities effectively:

1. **Logic View**:
    - Used for creating new activities and defining their relationships.
    - Activities are represented as icons, with connections illustrating their dependencies.
2. **Gantt Chart View**:
    - Displays activities as a list (on the left) and their time-based representation (on the right).
    - Parent tasks are shown in gray, while leaf tasks are represented in blue.
    - Activities can be moved, and durations can be adjusted directly within the Gantt chart, with changes automatically updated for all sub-activities.
3. **Line of Balance (LOB) View**:
    - A flow line diagram that illustrates the spatial and temporal progress of activities.

- Unlike Gantt charts, LOB does not present critical paths but provides insights into task overlap and crew pacing.
- Features such as Filter, Show Non-Working Hours, and Show Task Names enhance usability.
- Task parameters, such as type, duration, calendar, and constraints, can be edited directly in the LOB display.

Schedule Creation

The schedule creation process in BEXEL Manager is highly versatile and allows for automation and customization.

Creating a New Schedule Based on Predefined Selection Sets

This workflow combines elements of intelligent planning with traditional scheduling methods. Using predefined selection sets, planners can automatically generate schedule tasks linked to BIM elements. While task relationships are not automatically defined, they can be easily established in the Logic View, streamlining the process compared to traditional manual scheduling.

Creating Zones and Methodologies

Construction Zones and Methodologies form the foundation of intelligent scheduling. These concepts enable the creation of detailed 4D/5D BIM models with animations that reflect both spatial and temporal construction processes.

1. **Construction Zones (Spatial Distribution of Construction Works):**

Construction projects are divided into zones such as Buildings, Storeys, and Phases to optimize resource planning and task allocation.

- **Vertical Divisions** (e.g., Building Storeys):

Predefined by the number of levels in the building, simplifying planning and improving resource allocation.

- **Horizontal Divisions** (e.g., Work Phases):

Consider factors like work distribution, material quantities, and construction technologies. The goal is to ensure consistent resource utilization and efficient task execution, typically organized into weekly intervals.

- **Methodologies (Order of Work Execution):**

Construction methodology defines the sequence of work execution, including temporary and permanent works.

- **First-Level Methodology**: High-level classification of tasks.
- **Second-Level Methodology**: More detailed breakdown based on specific work requirements.

4.1.1.13 Schedule Optimization

Schedule optimization in BEXEL Manager focuses on improving project schedules to ensure efficient resource utilization, minimize delays, and achieve better project performance. Optimization can be achieved using tools like the LOB (Line of Balance) flow line diagram, automatic task duration calculation, and resource leveling.

1. Schedule Optimization Using Line of Balance (LOB)

The Line of Balance scheduling technique is particularly useful for linear and repetitive construction tasks. Key benefits include:

Crew Placement and Task Pacing:

- Determine optimal crew placement and pacing to ensure smooth task execution.
- Avoid disruptions by balancing resource allocation across repetitive tasks.

Visualization of Task Overlaps:

- Use dashed lines to identify areas where multiple tasks are performed simultaneously.
- Adjust task timing to avoid bottlenecks and improve workflow continuity.

2. Schedule Optimization Using Automatic Task Duration Calculation

Task durations can be optimized based on daily outputs, workforce productivity rates, and available resources.

Dynamic Task Duration Adjustment:

- Automatically calculate task durations based on actual quantities of work and resource availability.
- Ensure that task durations align with productivity rates, avoiding under- or over-allocation of resources.

Scenario Analysis: Test different resource configurations to identify the most efficient schedule.

3. Resource Leveling

Resource leveling ensures that resources are allocated efficiently across all activities, preventing over-allocation or under-utilization.

Key Features:

Balancing Resource Utilization: Adjust schedules to ensure uniform resource distribution throughout the project.

Avoiding Resource Conflicts: Resolve scheduling conflicts caused by limited resources, such as equipment or workforce constraints.

Improved Productivity: Optimize resource allocation to maintain consistent productivity rates across tasks.

The scheduling framework in BEXEL Manager provides a structured approach to creating, managing, and optimizing project schedules. By leveraging tools like Gantt Charts, Logic View, and Line of Balance, planners can visualize and refine construction workflows. Advanced features, such as automatic task duration calculation and resource leveling, enable efficient resource utilization and streamlined project execution. This framework ensures that schedules are optimized for both spatial and temporal requirements, contributing to the overall success of BIM-based construction projects.

4.1.1.14 Reporting and Analytics Framework in BIM Projects

The Reporting and Analytics capabilities in BEXEL Manager provide advanced tools to monitor project progress, analyze performance, and simulate construction schedules. These tools enable project teams to make data-driven decisions, ensure project alignment with planned goals, and provide insights into critical aspects of project execution. The following sections outline the frameworks for Reporting and Analytics, Progress Monitoring, and Schedule Simulation in BIM-based construction projects.

Reporting and Analytics

The Reporting and Analytics module in BEXEL Manager enables users to generate comprehensive reports and analyze project data across various dimensions, such as cost, time, and resource utilization. These features are essential for tracking performance, identifying risks, and ensuring project transparency.

Key Features of Reporting and Analytics

1. **Customizable Reports**:

- Reports can be tailored to meet specific project needs, focusing on cost, schedule, quantities, or other project parameters.
- Exportable formats include Excel (XLSX) and PDF, making data sharable across teams.

2. **Real-Time Data Visualization**:
   - Dashboards provide real-time insights into project performance, such as budget utilization, task completion, and resource allocation.
   - Charts and graphs are used to visually represent trends and key performance indicators (KPIs).
3. **Multi-Level Analysis**:
   - Drill down into specific project details, such as individual tasks or elements, to understand their impact on overall performance.
   - Analyze data at various levels, including project, building, storey, or zone.
4. **Templates and Automation**:
   - Reusable templates allow for consistent reporting across projects.
   - Automated report generation saves time and ensures accuracy.

5. **Integration with Other Modules**:

Reports are fully integrated with other BEXEL Manager modules, such as Quantity Takeoff (QTO), Cost Management, and Scheduling, ensuring comprehensive analysis.

Reporting and analysis using Power BI

Reporting and analysis through Power BI facilitates the transformation of extensive data layers from the BEXEL Manager platform into dynamic visual representations. As a comprehensive data analytics tool, Power BI empowers users to derive essential insights into projects via interactive dashboards. These dashboards integrate all Building Information Modeling (BIM) data, fostering transparent and effective decision-making grounded in data analytics.

4.1.1.15 Progress Monitoring Framework

Progress Monitoring is a vital part of project management, enabling teams to track construction progress, compare planned versus actual performance, and identify deviations early in the project lifecycle. In BEXEL Manager, progress monitoring integrates with the 4D BIM model to provide real-time updates and visual feedback.

Steps for Progress Monitoring

1. **Baseline Schedule Setup**:
   - Define a baseline schedule within the Schedule Editor to serve as a benchmark for tracking progress.
   - Link the baseline schedule to the 4D BIM model for visual comparison during monitoring.
2. **Progress Data Collection**:
   - Collect progress data on-site, including percentages of task completion, actual durations, and delays.
   - Input progress data into BEXEL Manager manually or import from external tools.
3. **Visualization of Progress**:
   - Use the 4D BIM model to visualize progress in real-time, comparing planned versus actual task completion.
   - Color-coded visualizations highlight completed, ongoing, and delayed tasks.
4. **Performance Dashboards**:
   - Monitor KPIs such as schedule variance and percentage of work completed using interactive dashboards.
   - Generate progress reports for stakeholders to provide updates on project performance.
5. **Deviation Analysis**:
   - Compare actual progress with the baseline to identify delays, resource shortages, or other issues.
   - Analyze the impact of deviations on the overall project timeline and cost.
6. **Integration with Cost Data**:
   - Link progress data with cost data to track expenditure against work completed.
   - Generate Earned Value Management (EVM) reports to assess project health.

4.1.1.16 Schedule Simulation Framework

Schedule Simulation allows project teams to test and analyze construction schedules in a virtual environment before actual implementation. This enhances decision-making by identifying potential risks, optimizing workflows, and improving resource allocation.

Key Features of Schedule Simulation

4D BIM Simulation:

- Link the construction schedule to the 3D BIM model to create a 4D simulation of the project.
- Visualize the sequence of construction activities and their spatial relationships over time.

Scenario Testing:

- Simulate multiple scheduling scenarios to identify the most efficient workflows.
- Test the impact of changing task durations, resource allocations, or construction sequences.

Critical Path Analysis:

- Visualize the critical path within the 4D simulation to understand which tasks have the greatest impact on the project timeline.
- Adjust task relationships and durations to optimize the critical path.

Resource Utilization Analysis:

- Simulate resource usage to ensure proper allocation and avoid overloading or underutilization.
- Balance resources across tasks to improve productivity and reduce costs.

Automation of Task Durations:

- Automatically adjust task durations based on daily outputs, workforce productivity rates, and actual quantities from the BIM model.

Visual Feedback:

- Use animations to visually analyze the construction process, identify bottlenecks, and understand spatial interdependencies.
- Highlight discrepancies between planned and actual schedules using color-coded visualizations.

Integration with Cost Data:

- Simulate cost impacts by linking the 4D model with cost data.
- Evaluate cash flow and budget implications for different scheduling scenarios.

Benefits of Reporting, Progress Monitoring, and Schedule Simulation

Improved Decision-Making: Data-driven insights from reports, dashboards, and simulations enable stakeholders to make informed decisions quickly.

Enhanced Collaboration: Visual reports and 4D simulations improve communication and understanding among project teams.

Risk Mitigation: Early identification of schedule delays and cost overruns allows for corrective actions before issues escalate.

Optimized Resource Management: Progress monitoring and simulation ensure efficient allocation of labor, materials, and equipment.

Transparency and Accountability: Comprehensive reporting provides stakeholders with clear updates on project performance, fostering accountability.

Figure 22 illustrates a 4D/5D BIM Construction Planning Workflow, integrating time (4D) and cost (5D) dimensions into the planning process. It begins with importing multiple IFC models and classifying cost and construction methodologies. Using tools like Bexel Viewer, the workflow automates schedule generation, clash detection, and visual simulations. Various schedule versions planned, actual, and progress-tracked are developed and optimized. Outputs, including KPIs, payment certificates, and AI/ML-enhanced dashboards, support decision-making and cross-project benchmarking, emphasizing a data-driven approach to project execution.

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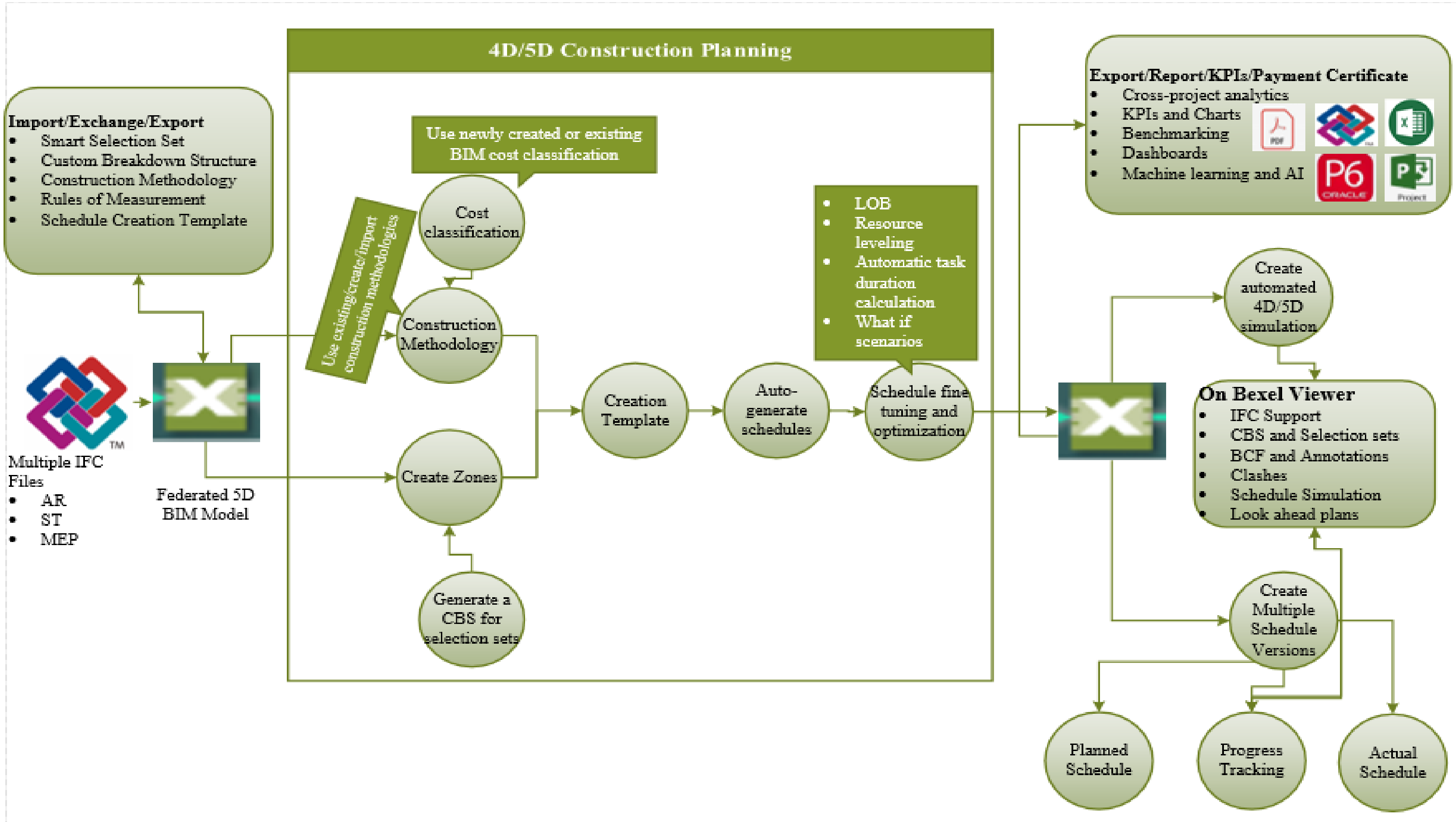


Figure 22 Scheduling /4D BIM Framework (Own Developed based on ISO19650 and Bexel Workflow)

Figure 23 illustrates a dual-structured framework combining BIM-based project information management processes with detailed technical execution planning. The left portion represents a structured BIM delivery workflow aligned with ISO 19650-1 and Ethiopian Standard ES 7030-7031, guiding the project through stages such as initiation, tendering, information development, review, and closeout. It emphasizes critical BIM documentation, approval gateways, and stakeholder responsibilities, ensuring information consistency and control across the asset lifecycle.

The right portion details the technical BIM execution workflow, showcasing how federated models are used for validation, clash detection, quantity takeoff, scheduling (4D), and cost classification (5D). Automation tools support progress tracking, simulation, and report generation, enabling informed, data-driven project delivery.

Together, these framework bridges high-level BIM information management strategies with operational-level digital practices to support standardized, transparent, and efficient project execution.

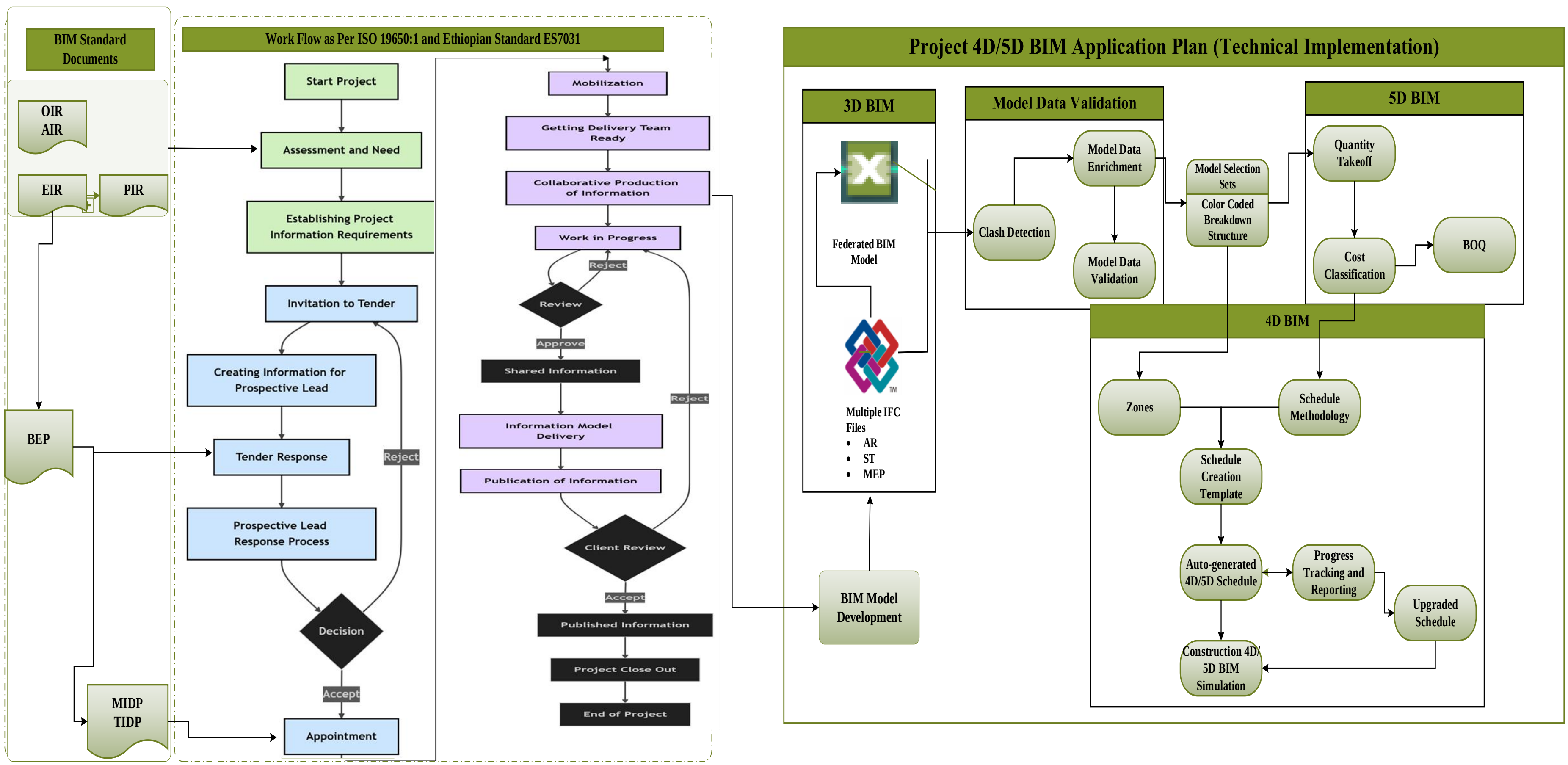


Figure 23 Integrated BIM Project Information Management and Technical Implementation Framework (Own Developed based on ISO19650, Ethiopian Standard ES 7030-7031 and Bexel Workflow)

5 APPLICATION OF THE FRAMEWORK: CASE STUDIES

This section outlines the application of the developed BIM implementation framework, aligned with ISO 19650, to the selected building projects, Project A, Project B and Project C, in Addis Ababa. The framework ensures structured workflows and processes for achieving the project's objectives, enhancing collaboration, and delivering a high quality, technologically advanced facility.

General

In the development of this thesis, selecting an appropriate 4D/5D Building Information Modeling (BIM) software was crucial to effectively integrate 3D, 4D, and 5D workflows, thereby enhancing project efficiency and accuracy. The chosen platform needed to provide a cloud-based environment to facilitate collaborative decision-making and comprehensive project control.

Software Selection Criteria:

1. **Integration of 3D, 4D, and 5D Workflows:** The software must support the creation and management of 3D models, link these models to 4D, and integrate 5D to enable dynamic project simulations and analyses.
2. **Educational Accessibility:** Availability of a free educational license was a key factor, as it ensures that students can access and utilize the software without financial constraints, thereby supporting academic research and learning.

Software Selection:

After evaluating various BIM software options, BEXEL Manager was selected for its comprehensive features and alignment with the outlined criteria:

Comprehensive 4D/5D BIM Capabilities: BEXEL Manager offers advanced 4D and 5D BIM functionalities, including automated scheduling, cost estimation, and progress monitoring, which are integral to the framework's implementation. (bexelmanager.com)

Educational License Availability: BEXEL Manager offers a one-year free educational license to full-time students and university professors, making it accessible for academic purposes. The application process requires verification of educational status through documents such as a student ID or enrollment letter. (bexelmanager.com).The implementation of the methodologies and workflows outlined in the thesis paper for managing and analyzing a federated Building Information Model (BIM) using BEXEL

Manager has demonstrated significant advancements in project management processes for Project A, Project B and Project C.

5.1 4D/5D BIM Implementation on Project A: The New Ethiopian National Theatre Project

Project Overview

The Ethiopian National Theater project represents a significant milestone in modern African architecture, aimed at delivering a state of the art performance space for cultural and artistic enrichment. The project scope includes:

Building Composition

The main building consists of 2 Basements + Ground Floor + 11 Floors with amount of 2.7 billion birr, incorporating various functional spaces for performances, administration, and public use.

Technological Advancement

Upon completion, the theater will become one of Africa's most advanced cultural facilities, integrating modern construction methods and BIM-based lifecycle management.

Project Timeline

- **Start Date**: February 2022
- **Expected Completion**: August 2025

Project Location

- Gambia St, Addis Ababa, Ethiopia

The implementation of the BIM framework focuses on achieving a high level of collaboration, accuracy and efficiency throughout the project lifecycle.

5.1.1 BIM Objectives and Use Cases

BIM Objectives

The implementation of BIM for the New Ethiopian National Theater Project focused on achieving specific objectives to enhance project efficiency, collaboration, and outcomes. These objectives were strategically prioritized based on their significance to the project’s success. Below is a detailed narrative, describing each objective along with its priority level based on the project BEP.

1. **Improve Quality and Consistency of Design (Priority: Medium)**

One of the key objectives of BIM implementation was to ensure accuracy and uniformity throughout the design process. By leveraging BIM tools, the project aimed to minimize errors, maintain consistency across design disciplines, and improve overall design quality. Although critical to the project's foundation, this objective was assigned a medium priority as other aspects, such as integration and planning, were deemed more urgent.

2. **Convert Conventional Designs to Integrated BIM (Priority: High)**

The project aimed to transition from traditional design approaches to fully integrated BIM workflows. This shift facilitated the creation of coordinated 3D models, enhancing collaboration and design integration across disciplines such as architecture, structural engineering, and MEP systems. However, the initial design, being a conventional one, did not account for certain undecided mechanical systems, which posed challenges in fully incorporating these systems into the BIM model. Despite this limitation, this objective was assigned a high priority, highlighting its critical role in achieving the project's goals of improved coordination and efficiency.

3. **Ensure Quality Control and Conformity (Priority: High)**

Maintaining quality control and conformity throughout the project was a high-priority objective. BIM tools were utilized to perform clash detection, model validation, and ensure adherence to established design standards.

4. **Coordinate Design and Construction Documentation (Priority: Medium)**

BIM was used to streamline the coordination between design and construction documentation, ensuring seamless workflows and reducing inconsistencies. By integrating design and construction teams through a centralized platform, the project achieved better alignment between design intent and physical construction. This objective was assigned a medium priority, as it was critical but less time-sensitive compared to other high-priority goals.

5. **Apply BIM for Methods and Planning (Priority: High)**

A high-priority objective was to leverage BIM for enhancing construction methods and planning. However, at the time of this research, there was no dedicated personnel assigned to this task. Consequently, I collaborated with the project team and took on the role of BIM Task Team Member for Project Management, with a specific focus on 4D (time) and 5D (cost) BIM. The integration of 4D and 5D BIM, which represents the primary focus of this thesis, is presented in the following sections. This objective was integral to achieving efficient project delivery and minimizing delays.

6. Facilitate Effective Stakeholder Communication (Priority: High)

Improving collaboration and communication among stakeholders throughout all project phases was identified as a high-priority objective. By using a Common Data Environment (CDE), stakeholders will able to access real-time project data, resolve issues collaboratively, and make informed decisions. This objective was critical to ensuring transparency and fostering teamwork across all disciplines.

7. Deliver Accurate As-Built Models (Priority: High)

The delivery of high-quality as-built models was another high-priority objective, aimed at supporting efficient facility management and operations post-construction. By integrating accurate as-built documentation into the BIM workflows, the project will ensure a reliable foundation for the building's lifecycle management. This objective emphasized the long-term value of BIM for asset maintenance and operational efficiency.

BIM Use Cases

To achieve the objectives, specific BIM use cases were identified and implemented. These use cases were selected to address critical project requirements and ensure the effective application of BIM throughout the project lifecycle.

Table 5-1 BIM EIR and Use Cases

Primary Objective (EIR)	Key BIM Uses	Value Rating	Responsible Team	Key Benefits
1. Digital Design & Documentation	• BIM Model Authoring •Documentation & Drawings	High	AR/ST/MEP	• Enhanced design visualization • Improved stakeholder collaboration • Automated document generation
2. Schedule & Cost Management	• 4D Planning • 5D Cost Estimation	High	BIM Project Management	• Automated quantity takeoff & Dynamic phasing plans • Real-time cost tracking & Resource optimization
3. Quality Control	• Clash Detection • Code Validation • Coordination	High	BIM Management	• Reduced field conflicts • Early error detection • Improved construction quality • Decreased RFIs
4. Productivity Enhancement	• Digital Fabrication • Design Reviews	Medium	MEP/All Teams	• Streamlined fabrication • Efficient design review process • Reduced mock-up costs
5. Stakeholder Communication	• Common Data Environment (CDE) • Design Reviews	Medium	All Teams	• Improved collaboration • Real-time feedback • Enhanced decision-making
6. Facility Management	• Record Modeling• COBie Data Set	Medium	BIM Management	• As-built documentation • FM integration capability

5.1.2 BIM Management

Roles and Responsibilities

To ensure effective BIM implementation, the project team structure was defined with clear roles and responsibilities:

Table 5-2 Roles and Responsibilities of BIM Management Crew

Role	Responsibilities
Project BIM Manager	Develop and enforce the BIM Execution Plan (BEP), align BIM processes with objectives, and oversee quality.
BIM Manager-Contributor	Manage BIM workflows within their organization and collaborate with the Project BIM Manager.
Project BIM Coordinator	Deliver BIM outputs, conduct model audits, and ensure adherence to BEP standards.
BIM Task Team	Model elements, generate documentation, and follow project guidelines
CDE Controller	Maintain the Common Data Environment (CDE), ensure document conformity, and manage naming conventions.

This structured hierarchy ensures that all stakeholders are aligned with the project objectives and processes.

5.1.3 BIM Maturity

The project follows ISO 19650-compliant stage 2 BIM maturity, emphasizing shared models, interoperability using IFC standards, and a centralized Common Data Environment (CDE) for collaboration.

5.1.4 BIM Software and Tools

Table 5-3 Software Schedule for the Project

Table SOFTWARE SCHEDULE							
No.	**Task team**	**Task**	**Software**	**No of license**	**Version**	**Native format**	**Exchange format**
1	Project-BIM management	Discipline Coordination	Bexel manager	2	V20.1/	*.bx3	*.IFC *.PDF
		Model checking/ validation	Solibri office	1	V 9.12	*.SMC	*.IFC *.PDF
		CDE management/local server	Server 2000	1			
2	Architectural	Modeling	Autodesk Revit	9	2023	*.RVT	*.IFC *.PDF
3	Structural /Civil	Modeling Structural	Autodesk Revit		2023	*.RVT	*.IFC *.PDF
4	MEP	Electrical Modeling	Autodesk Revit		2023	*.RVT	*.IFC *.PDF
		Mechanical Modeling	Autodesk Revit		2023	*.RVT	*.IFC *.PDF
		Sanitary and plumbing modeling	Autodesk Revit		2023	*.RVT	*.IFC *.PDF
		Digital Fabrication	Autodesk-CamCAD	1	2023	*.CAD	*.IFC *.PDF
5	Project Management	4D/5D modeling	Bexel manager		2023	*.bx3	*.IFC *.PDF

5.1.5 Common Data Environment (CDE)

The project uses the **Greed Platform** for collaboration and data sharing. Key features include:

- Upload and approval of 3D/2D deliverables.
- IFC visualization and BCF issue tracking.
- Documentation traceability and decision management.

5.1.6 Quality Control and Clash Detection

Monthly Clash Detection: Conducted using Solibri Office, with results documented in the CDE.

Issue Resolution: BIM review meetings address detected clashes, and resolutions are shared as BCF tasks.

5.1.7 Modeling Rules and Standards

Classification Systems: OmniClass, MasterFormat, UniFormat.

File Naming Convention: Defined using ISO 19650 standards, ensuring consistency across disciplines.

Metadata and LOD: Models are developed to LOD 300-500, with clear documentation of non-graphic metadata for facility management.

By implementing this BIM framework, the Ethiopian National Theater project integrates cutting-edge design, construction, and management practices. The application of ISO 19650 ensures a structured and collaborative approach, enhancing project efficiency, reducing risks, and delivering an advanced cultural facility for Ethiopia.

5.1.8 4D/5D BIM Process: The Implementation

The implementation of the developed BIM framework for the Ethiopian National Theater Project requires a structured collaboration and coordination process. This section focuses on the process of model sharing, collaborative workflows, and the use of the Common Data Environment (CDE) platform to ensure seamless communication and interoperability between all project stakeholders.

Process and Collaborative Platform

The collaborative framework ensures that all disciplines architectural, structural, MEP, and project management—work in an integrated manner. The coordination relies on monthly BIM review meetings, where models are analyzed, coordinated, and updated based on feedback. To facilitate collaboration and interoperability, the following standards and tools are implemented:

Model Exchange Format: All models will be exchanged in IFC (Industry Foundation Classes) format, ensuring interoperability across different software platforms and tools.

Issue Management Format: Comments and issues identified during quality reviews and clash detection will be shared in BCF (BIM Collaboration Format), enabling structured communication and traceability of decisions.

Common Data Environment (CDE): The Greed Platform is used as the centralized CDE for sharing, storing, and managing models, documents, and issues.

Roles and Access Levels in the CDE Platform

To maintain control and ensure accountability, specific roles and access levels are assigned to participants within the CDE:

1. **Project BIM Manager and BIM Coordinator (Administrators)**

Responsibilities:

Create and manage project folders, providing access to contributors as needed.

- Assign tasks and create issue lists for quality control, clash detection, and floor-by-floor coordination.
- Monitor the upload, review, and approval process of models and documents.
- Ensure compliance with file naming conventions and metadata requirements.
- Resolve conflicts related to the deletion or modification of models, documents, or issues.

2. **Contributors (Members)**

Responsibilities:

- Submit their discipline-specific models to the CDE.
- Review and address issues raised by the Project BIM Manager or Coordinator.
- Upload supporting documents (e.g., drawings and specifications) in approved formats (PDF, DWG, or IFC).
- Update models and resubmit them based on the feedback received during BIM reviews.

Access Restrictions for Contributors:

- Contributors will have “member” access, which limits their ability to delete or modify files, documents, or BCF issues without administrator approval. This ensures that data integrity is maintained and unauthorized changes are prevented.

Process to Share Models

The following process outlines the structured approach for sharing models in the **Ethiopian National Theater Project**:

Step 1: Preparation of Models

- Each discipline (architectural, structural, MEP) creates their models using their respective tools (e.g., Autodesk Revit, BEXEL Manager).
- Models must comply with the agreed Level of Development (LOD) requirements, metadata standards, and file naming conventions defined in the BIM Execution Plan (BEP).

Step 2: Exporting Models in IFC Format

- Models are exported in IFC2x3 format to ensure compatibility across tools used by other disciplines.
- Discipline-specific settings are applied during the export process to include only the relevant geometry, properties, and metadata required for coordination.

Step 3: Uploading Models to the CDE

- Contributors upload their discipline-specific models to the designated folders in the CDE platform (Greed).
- File naming conventions are strictly followed, including project codes, originator codes, volume, level/location, discipline, and file type.
- Metadata such as status codes (e.g., S0 for "Work in Progress" or S1 for "Suitable for Coordination") are included during the upload process to indicate the purpose and readiness of the model.

Step 4: Quality Control and Validation

- The Project BIM Manager reviews the uploaded models for compliance with project standards, clash detection, and quality control.
- Issues identified during the review are documented in BCF format and shared with the contributors through the CDE.

Step 5: Issue Resolution and Model Updates

- Contributors download the BCF issues from the CDE and address the comments or clashes in their models.
- Updated models are re-exported in IFC format and re-uploaded to the CDE with the appropriate metadata (e.g., updated status codes).

Step 6: Monthly BIM Review and Coordination

- During the monthly BIM review meetings, updated models are federated into a single coordinated BIM model.
- The federated model is analyzed for overall compliance, and task progress is reviewed.
- Additional issues, if identified, are documented in the CDE for resolution.

Model Coordination and Federated Model Creation

Federated Model Workflow:

1. The Project BIM Coordinator combines discipline-specific IFC models into a federated BIM model using coordination tools such as BEXEL Manager or Solibri Office.
2. The federated model is analyzed for:
   - **Clash Detection**: Identifying and resolving conflicts between disciplines (e.g., structural beams intersecting MEP ducts).
   - **Spatial Coordination**: Ensuring that all components are correctly placed within the defined zones and levels.
   - **Compliance**: Verifying adherence to project standards, including metadata, LOD, and file naming conventions.

Issue Management through BCF Format

Effective issue management ensures that all identified problems are resolved efficiently:

Issue Creation: Issues are created in BCF format, which includes critical information such as the location of the issue, a description, and screenshots.

Issue Assignment: Issues are assigned to the relevant discipline or contributor via the CDE platform.

Resolution Tracking: The CDE platform tracks the status of each issue (e.g., "Open," "In Progress," "Closed") to ensure accountability and progress transparency.

Communication and Collaboration

The collaborative process is facilitated through the CDE platform, ensuring real-time communication and data sharing:

- **Notifications**: Contributors receive automated notifications for new issues, updates, or approvals.

- **Traceability**: All actions, such as uploads, downloads, and modifications, are recorded for accountability and transparency.
- **Coordination Meetings**: BIM review meetings are conducted monthly, where the federated model is reviewed, and progress is discussed.
- **Improved Coordination**: Regular BIM reviews and issue tracking ensure timely resolution of clashes and alignment of models.

By following this structured approach, the Ethiopian National Theater Project will achieve a collaborative and efficient BIM implementation, ensuring high-quality deliverables and streamlined project execution.

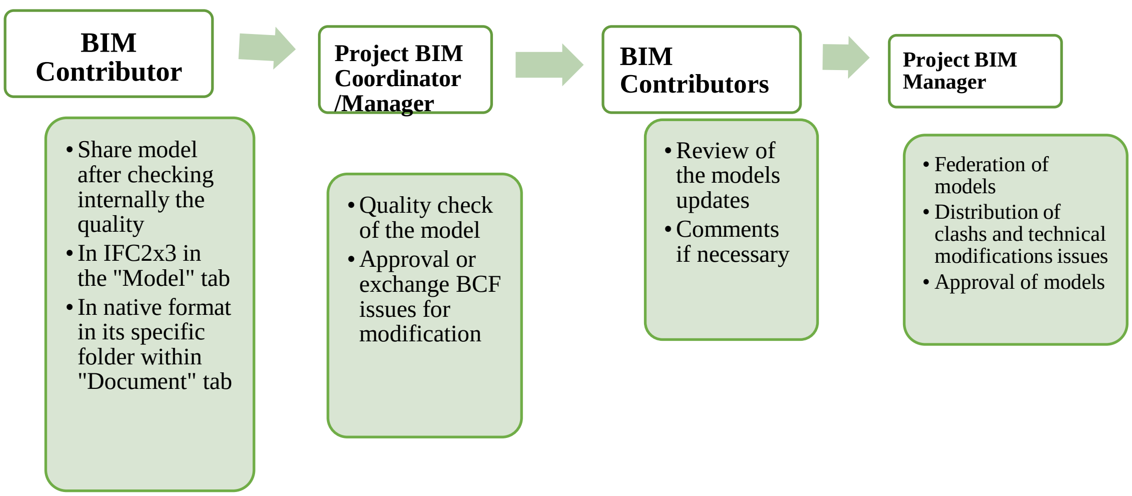


Figure 24 Process to share models for 4D/5D BIM Implementation

5.1.8.1 Creating a Project and Managing Model Data in BEXEL Manager

The integration of multiple data sources into a federated BIM model using BEXEL Manager enabled seamless collaboration and data management. The Revit Publisher was instrumental in exporting models into BX3 format, ensuring that object geometry and metadata were preserved.

Results:

Efficient Data Consolidation: The federated model provided a comprehensive and unified view of all project components, significantly improving cross-disciplinary coordination.

Preservation of Metadata: Exporting to BX3 format retained critical information such as object properties, classifications, and relationships, which were vital for downstream analyses.

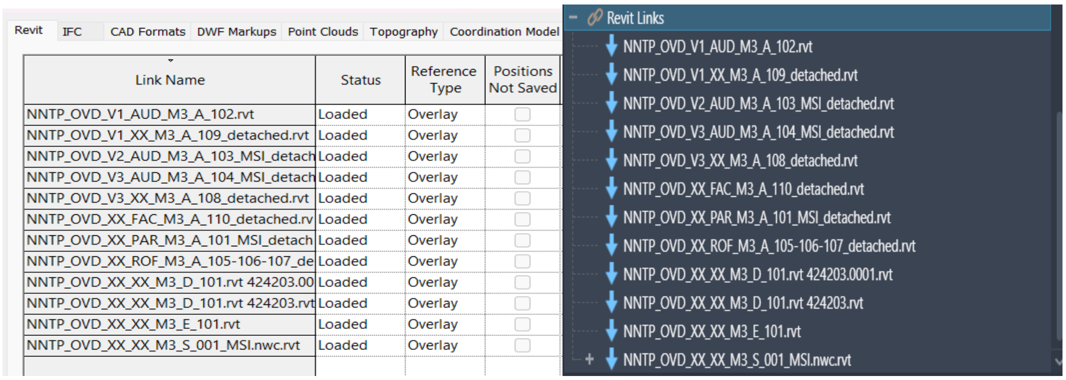


Figure 25 Federated BIM Revit Models

General Project Information

The Project

The project is visually represented through a detailed 3D model that captures various perspectives, including the front, back, top, left, and right views. This multidimensional representation serves not only as a design tool but also as an essential component for stakeholder communication and engagement. The 3D model serves as a pivotal resource in the project implementation phase, allowing for precise visualizations that inform structural decisions and enhance collaborative efforts among design, engineering, and construction teams. Each view of the model highlights specific architectural features, such as the façade.

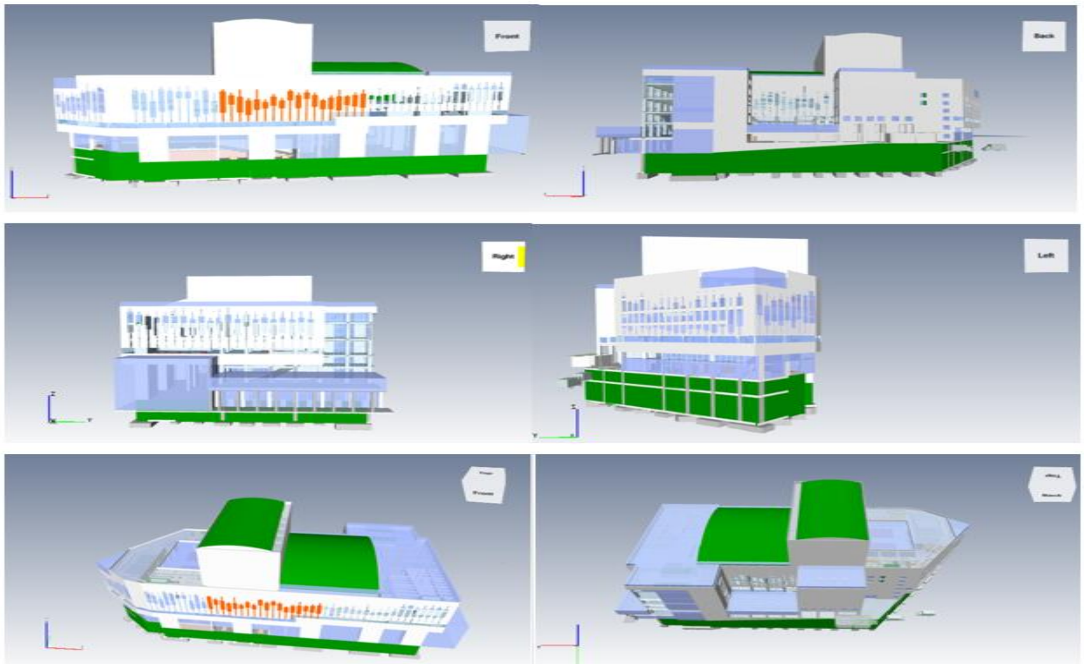


Figure 26 3D Model View of Project A

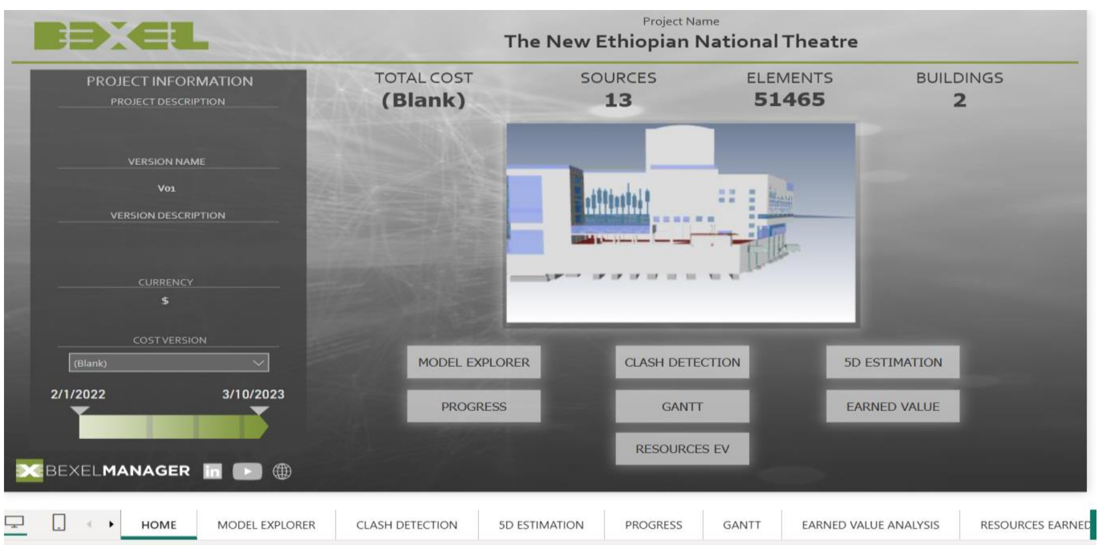


Figure 27 Statistics Information of Project A

Model Data Management

Building Explorer Palette

The Building Explorer palette in BEXEL Manager allowed the project team to navigate and organize model elements efficiently. By categorizing components hierarchically, the team could access and analyze specific elements quickly.

Results:

Hierarchical Data Organization: Enabled the creation of logical breakdown structures for better model navigation.

Custom Selection Sets: Tailored selection sets (regular and smart) improved efficiency by grouping elements based on criteria such as material, location, or discipline.

Smart Selection Sets

Smart selection sets were particularly effective as they dynamically updated to reflect changes in the model over time.

Results:

Consistency and Accuracy: Smart selection sets ensured that analyses were always performed on the most up-to-date data.

Automation: Reduced manual effort in maintaining selection sets, saving time and minimizing errors.

Initial Model Review

The Initial Model Review conducted in BEXEL Manager provided insights into model sources, organization, accuracy, and level of detail (LOD).

Key Findings:

Model Sources: Models were successfully imported from Revit, with all geometry and metadata intact.

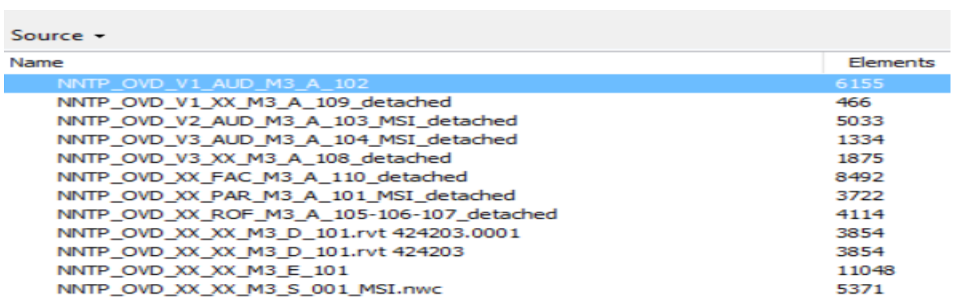


Figure 28 Model Sources of Project A

Model Organization: Consistent file naming conventions and metadata standards facilitated streamlined coordination.

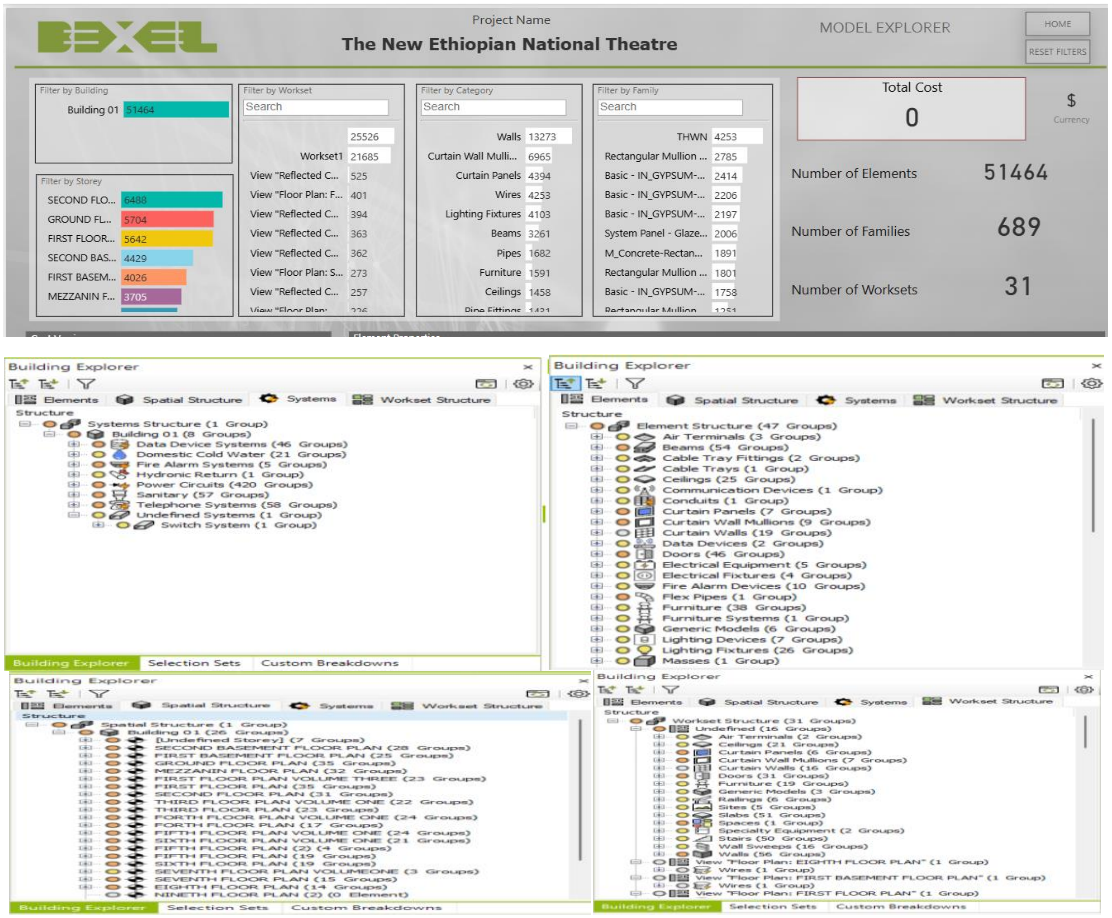


Figure 29 Model organization, Naming Conventions and Metadata Standards of Project A

Model Accuracy: Automated checks revealed minor inconsistencies, which were resolved early in the project lifecycle.

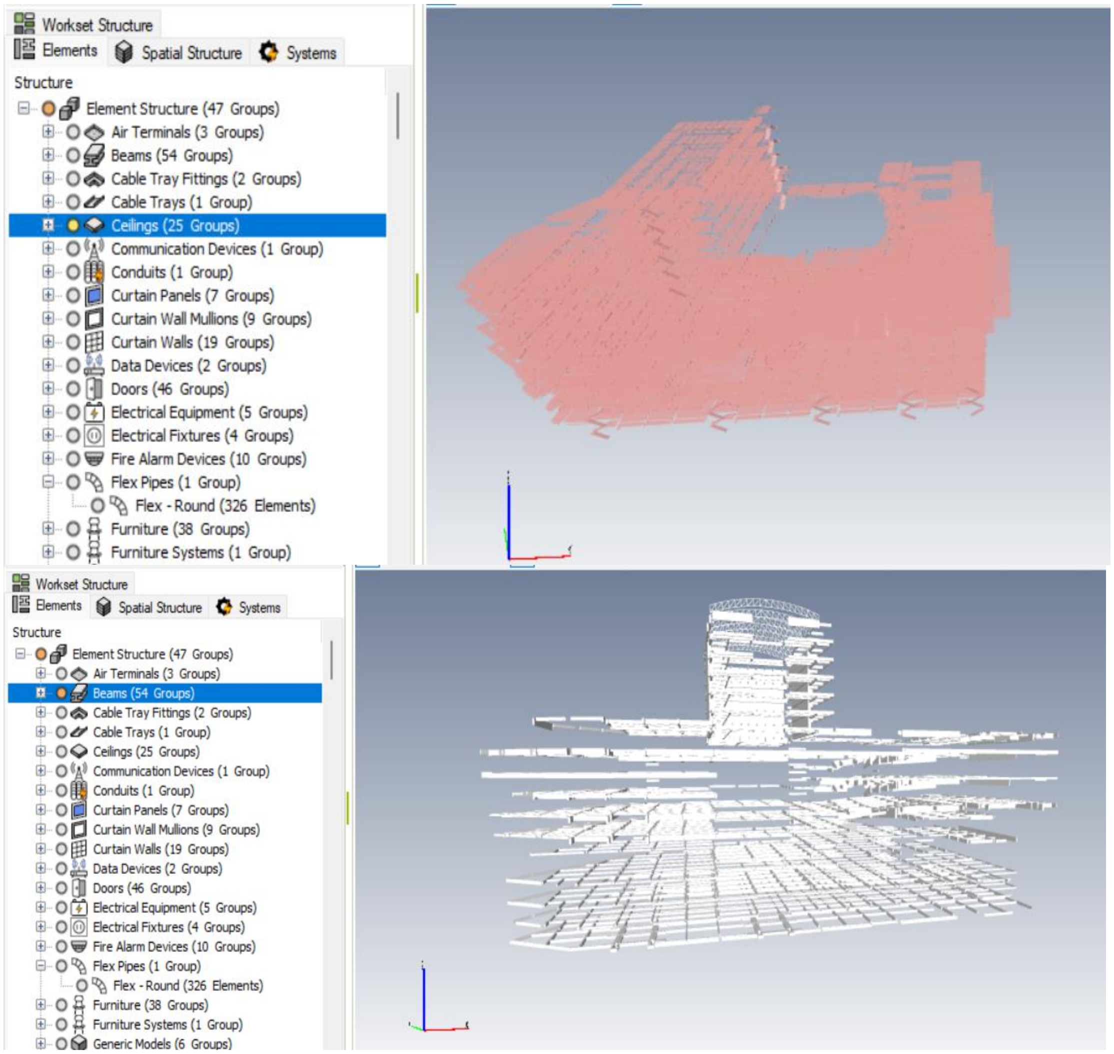
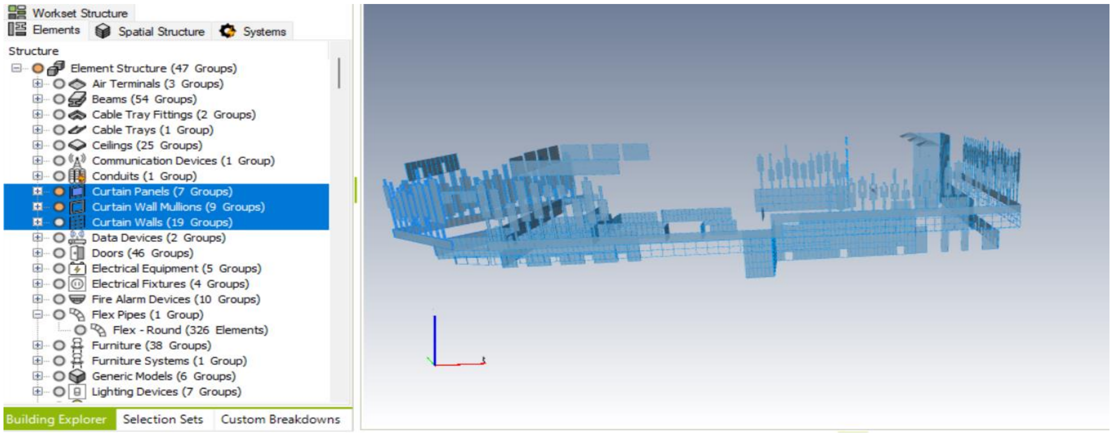


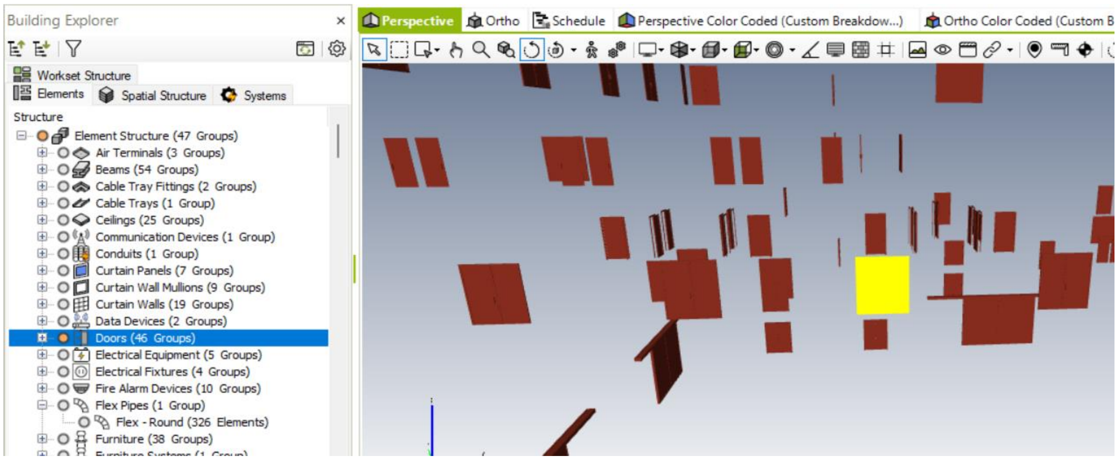
Figure 30 Model Accuracy of Project A

Visual Inspection:

Visual inspection is highly effective in helping to inspect spatial structures, elements, and systems within a BIM model. It plays a vital role in ensuring that all building components are accurately represented and properly coordinated.

Figure 31 illustrates visually Inspected BIM models of Project A.


Workset Structure
Elements
Spatial Structure
Systems
Structure
Element Structure (47 Groups)
Air Terminals (3 Groups)
Beams (54 Groups)
Cable Tray Fittings (2 Groups)
Cable Trays (1 Group)
Ceilings (25 Groups)
Communication Devices (1 Group)
Conduits (1 Group)
Curtain Panels (7 Groups)
Curtain Wall Mullions (9 Groups)
Curtain Walls (19 Groups)
Data Devices (2 Groups)
Doors (46 Groups)
Electrical Equipment (5 Groups)
Electrical Fixtures (4 Groups)
Fire Alarm Devices (10 Groups)
Flex Pipes (1 Group)
Flex - Round (326 Elements)
Furniture (38 Groups)
Furniture Systems (1 Group)
Generic Models (6 Groups)
Lighting Devices (7 Groups)
Building Explorer
Selection Sets
Custom Breakdowns


Building Explorer
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Element Structure (47 Groups)
Air Terminals (3 Groups)
Beams (54 Groups)
Cable Tray Fittings (2 Groups)
Cable Trays (1 Group)
Ceilings (25 Groups)
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Conduits (1 Group)
Curtain Panels (7 Groups)
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Curtain Walls (19 Groups)
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Electrical Equipment (5 Groups)
Electrical Fixtures (4 Groups)
Fire Alarm Devices (10 Groups)
Flex Pipes (1 Group)
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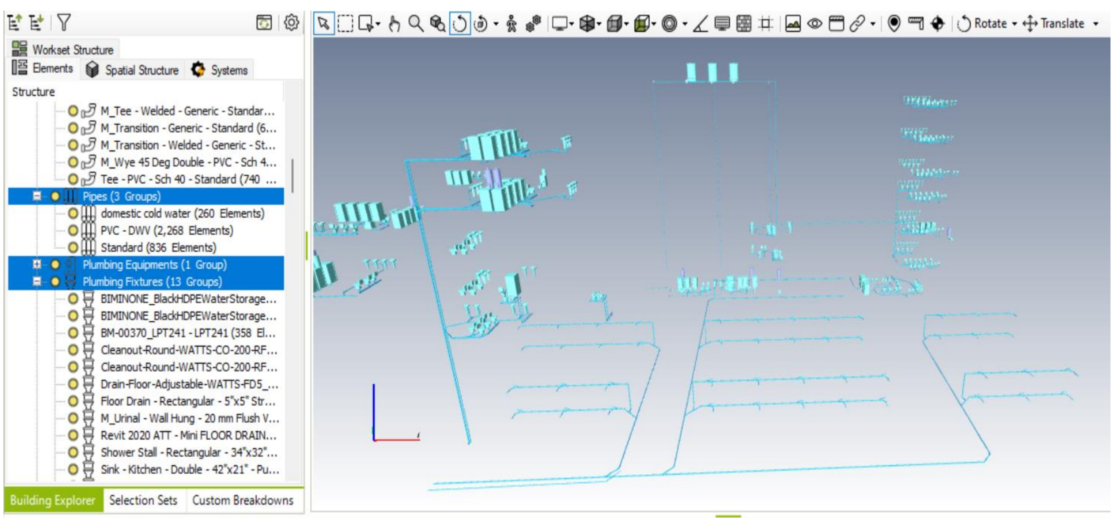

Workset Structure
Elements
Spatial Structure
Systems
Structure
M_Tee - Welded - Generic - Standar...
M_Transition - Generic - Standard (6...
M_Transition - Welded - Generic - St...
M_Wye 45 Deg Double - PVC - Sch 4...
Tee - PVC - Sch 40 - Standard (740 ...
Pipes (3 Groups)
domestic cold water (260 Elements)
PVC - DWV (2,268 Elements)
Standard (836 Elements)
Plumbing Equipments (1 Group)
Plumbing Fixtures (13 Groups)
BIMINONE_BlackHDPEWaterStorage...
BIMINONE_BlackHDPEWaterStorage...
BM-00370_LPT241 - LPT241 (358 El...
Cleanout-Round-WATTS-CO-200-RF...
Cleanout-Round-WATTS-CO-200-RF...
Drain-Floor-Adjustable-WATTS-FD5_...
Floor Drain - Rectangular - 5"x5" Str...
M_Urinal - Wall Hung - 20 mm Flush V...
Revit 2020 ATT - Mini FLOOR DRAIN...
Shower Stall - Rectangular - 34"x32"...
Sink - Kitchen - Double - 42"x21" - Pu...
Building Explorer
Selection Sets
Custom Breakdowns
Rotate
Translate

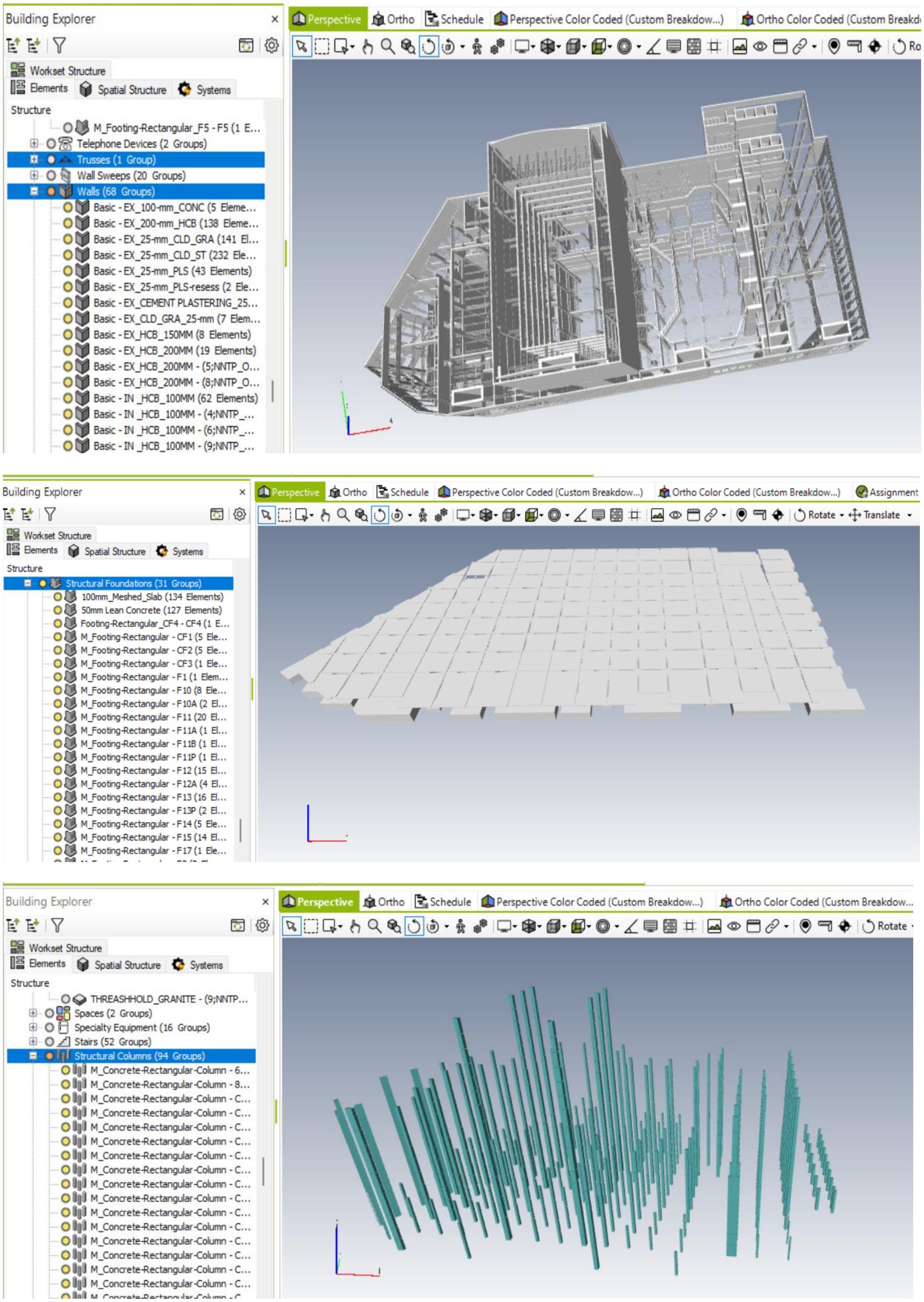


Figure 31 Visual Inspection of the Model A

Level of Detail (LOD): The model adhered to the required **LOD 300-400**, ensuring sufficient detail for construction planning and analysis.

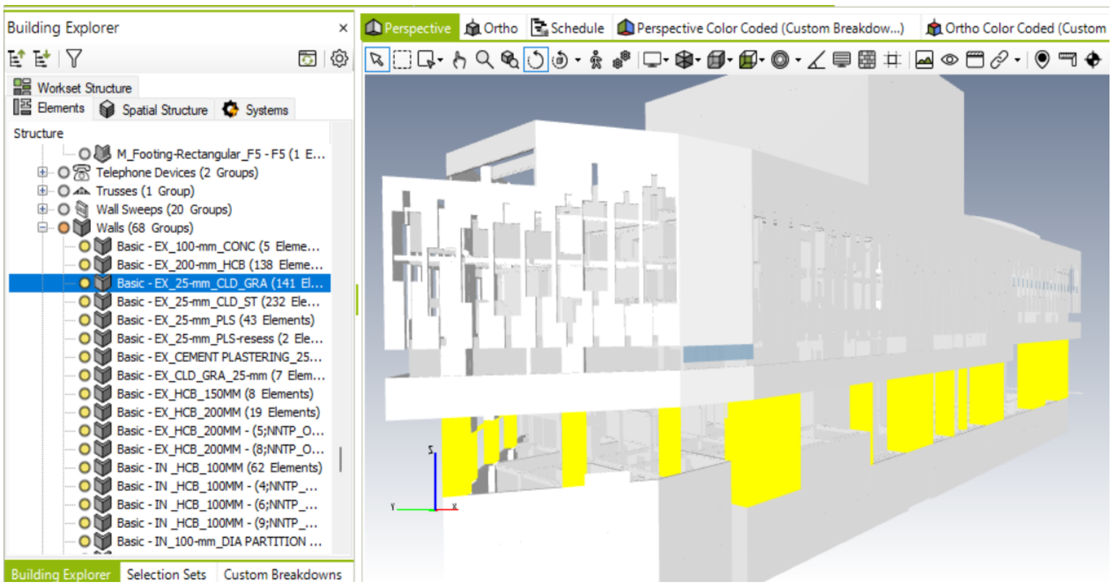


Figure 32 Sample LOD of the Model A

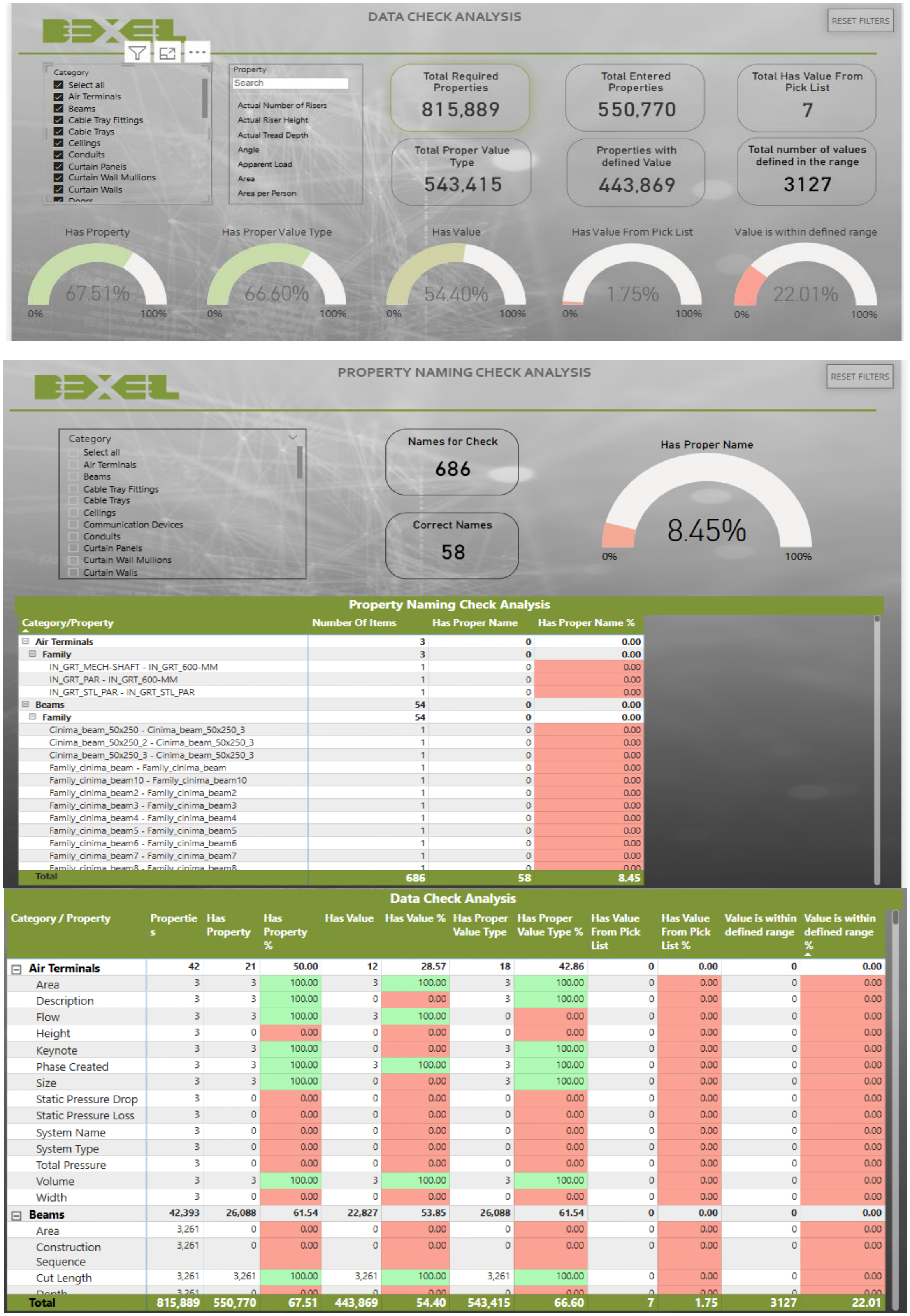
Results:

- Early identification of issues minimized delays in later project phases.
- Enhanced model quality provided a strong foundation for downstream processes, such as clash detection and quantity takeoff.

In BIM model data management, visual inspection complements automated processes by providing a human perspective to identify issues that might be missed by software. It is a critical step in maintaining the quality, accuracy, and reliability of BIM data, ultimately contributing to the successful delivery of construction projects.

5.1.8.2 Automated Data Validation Process

The automated data validation process ensured that models adhered to predefined standards, including IFC compliance, metadata accuracy, and file naming conventions.



Property Naming Check Analysis

Category/Property	Number Of Items	Has Proper Name	Has Proper Name %
⊟ **Air Terminals**	**3**	**0**	**0.00**
⊟ **Family**	**3**	**0**	**0.00**
IN_GRT_MECH-SHAFT - IN_GRT_600-MM	1	0	0.00
IN_GRT_PAR - IN_GRT_600-MM	1	0	0.00
IN_GRT_STL_PAR - IN_GRT_STL_PAR	1	0	0.00
⊟ **Beams**	**54**	**0**	**0.00**
⊟ **Family**	**54**	**0**	**0.00**
Cinima_beam_50x250 - Cinima_beam_50x250_3	1	0	0.00
Cinima_beam_50x250_2 - Cinima_beam_50x250_3	1	0	0.00
Cinima_beam_50x250_3 - Cinima_beam_50x250_3	1	0	0.00
Family_cinima_beam - Family_cinima_beam	1	0	0.00
Family_cinima_beam10 - Family_cinima_beam10	1	0	0.00
Family_cinima_beam2 - Family_cinima_beam2	1	0	0.00
Family_cinima_beam3 - Family_cinima_beam3	1	0	0.00
Family_cinima_beam4 - Family_cinima_beam4	1	0	0.00
Family_cinima_beam5 - Family_cinima_beam5	1	0	0.00
Family_cinima_beam6 - Family_cinima_beam6	1	0	0.00
Family_cinima_beam7 - Family_cinima_beam7	1	0	0.00
Family_cinima_beam8 - Family_cinima_beam8	1	0	0.00
Total	**686**	**58**	**8.45**

Data Check Analysis

Category / Property	Properties	Has Property	Has Property %	Has Value	Has Value %	Has Proper Value Type	Has Proper Value Type %	Has Value From Pick List	Has Value From Pick List %	Value is within defined range	Value is within defined range %
⊟ **Air Terminals**	**42**	**21**	**50.00**	**12**	**28.57**	**18**	**42.86**	**0**	**0.00**	**0**	**0.00**
Area	3	3	100.00	3	100.00	3	100.00	0	0.00	0	0.00
Description	3	3	100.00	0	0.00	3	100.00	0	0.00	0	0.00
Flow	3	3	100.00	3	100.00	0	0.00	0	0.00	0	0.00
Height	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Keynote	3	3	100.00	0	0.00	3	100.00	0	0.00	0	0.00
Phase Created	3	3	100.00	3	100.00	3	100.00	0	0.00	0	0.00
Size	3	3	100.00	0	0.00	3	100.00	0	0.00	0	0.00
Static Pressure Drop	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Static Pressure Loss	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
System Name	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
System Type	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total Pressure	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Volume	3	3	100.00	3	100.00	3	100.00	0	0.00	0	0.00
Width	3	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
⊟ **Beams**	**42,393**	**26,088**	**61.54**	**22,827**	**53.85**	**26,088**	**61.54**	**0**	**0.00**	**0**	**0.00**
Area	3,261	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Construction Sequence	3,261	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Cut Length	3,261	3,261	100.00	3,261	100.00	3,261	100.00	0	0.00	0	0.00
Depth	3,261	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	**815,889**	**550,770**	**67.51**	**443,869**	**54.40**	**543,415**	**66.60**	**7**	**1.75**	**3127**	**22.01**

Figure 33 Summarized Data Check Analysis Results of Project A

Results:

Error Reduction: Automated validation identified and corrected over 90% of data inconsistencies during the initial review phase.

Improved Interoperability: Ensured that models were compatible across tools and disciplines, reducing coordination issues.

5.1.8.3 Automated Model Data Enrichment

Automated data enrichment processes, such as assigning missing properties and classifications, streamlined the preparation of the model for analysis.

Results:

Enhanced Model Usability: Enrichment added value by filling gaps in metadata, enabling more robust analyses.

Increased Efficiency: Automation reduced manual effort and eliminated the risk of human error in data entry.

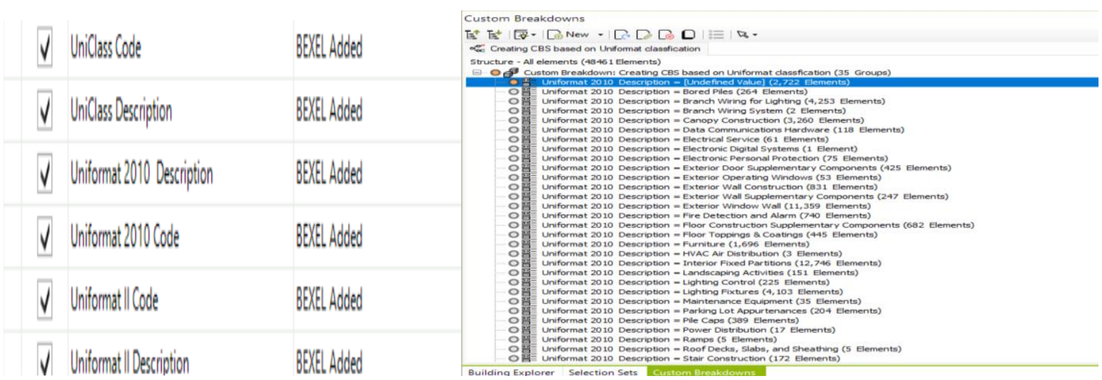


Figure 34 Automated Model Data Enrichment Result of Project A

5.1.8.4 Clash Detection

The clash detection tools in BEXEL Manager were used to identify and resolve conflicts between disciplines.

Process

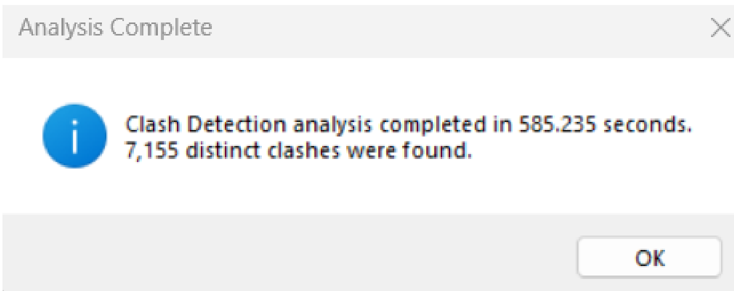
Automated Detection: The federated model was analyzed using BEXEL Manager's clash detection tools, which identified spatial conflicts between various building elements.

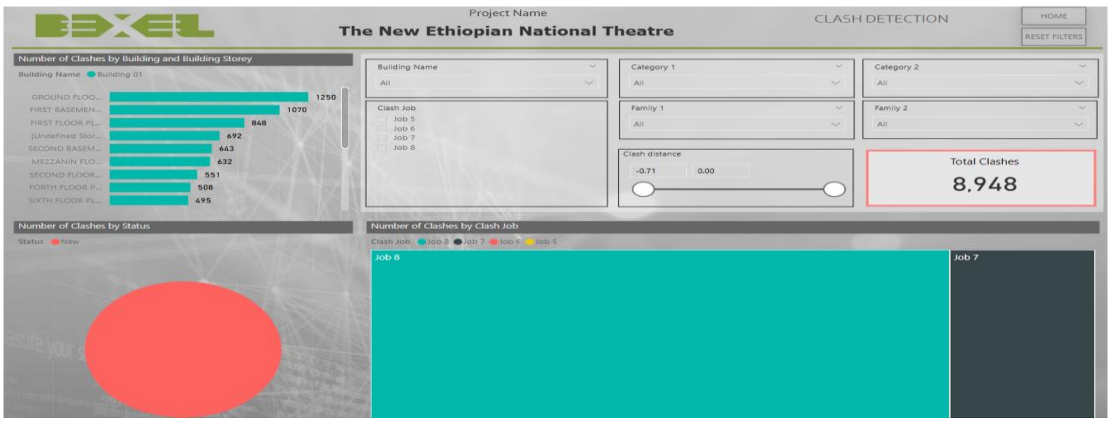
Categorized Clashes: Clashes were categorized based on severity and type (e.g., hard clashes, soft clashes, or workflow clashes).

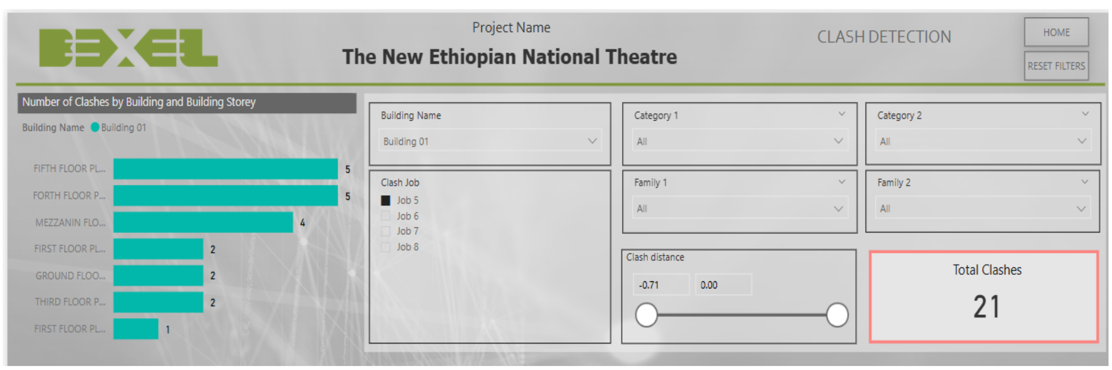
BCF Reports: Clash issues were exported in BCF format and shared with responsible teams for resolution.

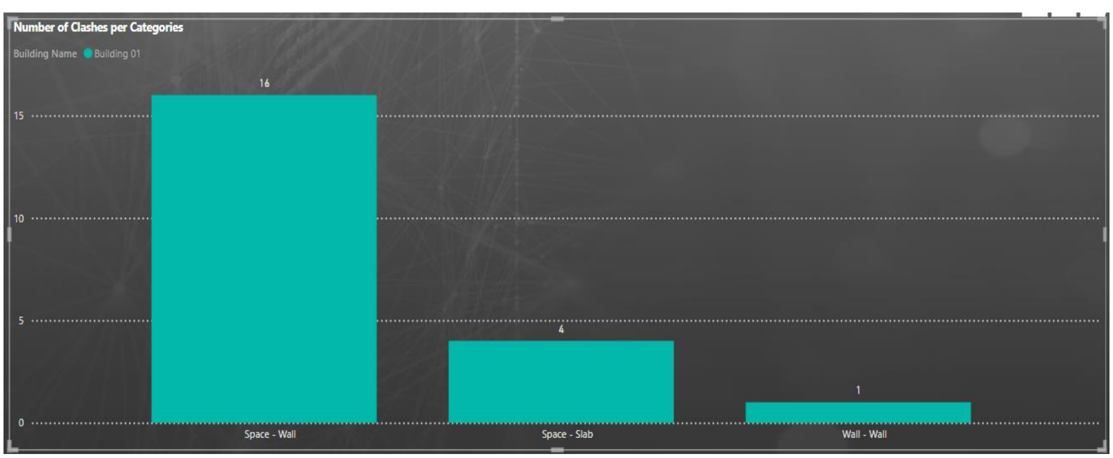
Key Findings:

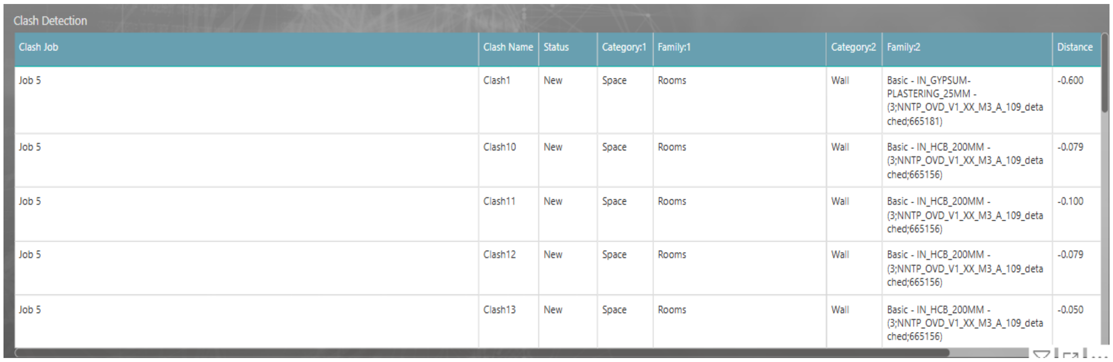
Clashes Detected: Over 8,948 clashes were identified during the first round of coordination within 10 minutes.











Clash Detection

Clash Job	Clash Name	Status	Category:1	Family:1	Category:2	Family:2	Distance
Job 5	Clash1	New	Space	Rooms	Wall	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_M3_A_109_detached;665181)	-0.600
Job 5	Clash10	New	Space	Rooms	Wall	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detached;665156)	-0.079
Job 5	Clash11	New	Space	Rooms	Wall	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detached;665156)	-0.100
Job 5	Clash12	New	Space	Rooms	Wall	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detached;665156)	-0.079
Job 5	Clash13	New	Space	Rooms	Wall	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detached;665156)	-0.050

Figure 35 First Round Clash Detection Results of Project A

Clash Resolution: Approximately 81% of clashes were resolved within two months of identification, with the remainder addressed in subsequent iterations. Within two months, using a collaborative process facilitated through the Common Data Environment (CDE)**.** Remaining issues were addressed in subsequent iterations.

Figure 36 Resolved Clashes with Subsequent Iterations of Project A

Results:

Reduced Rework: Early detection prevented costly and time-consuming rework during construction.

Improved Coordination: Disciplines worked more effectively, ensuring that their models were updated and aligned after each clash resolution.

5.1.8.5 Automated Quantity Takeoff Generation

Automated **Quantity Takeoff (QTO)** in BEXEL Manager leveraged the enriched BIM model to extract precise quantities of materials and elements required for construction. This automated process replaced traditional manual methods, ensuring accuracy and reducing time.

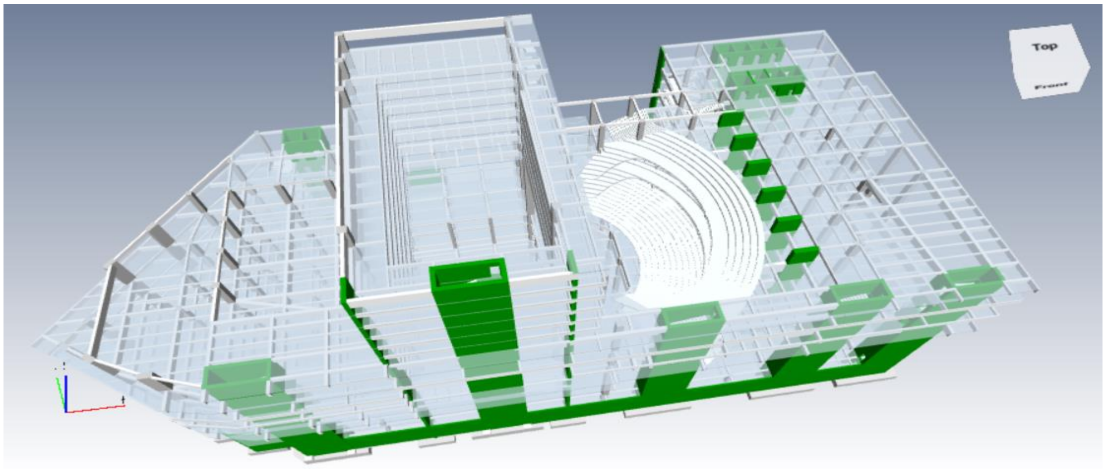


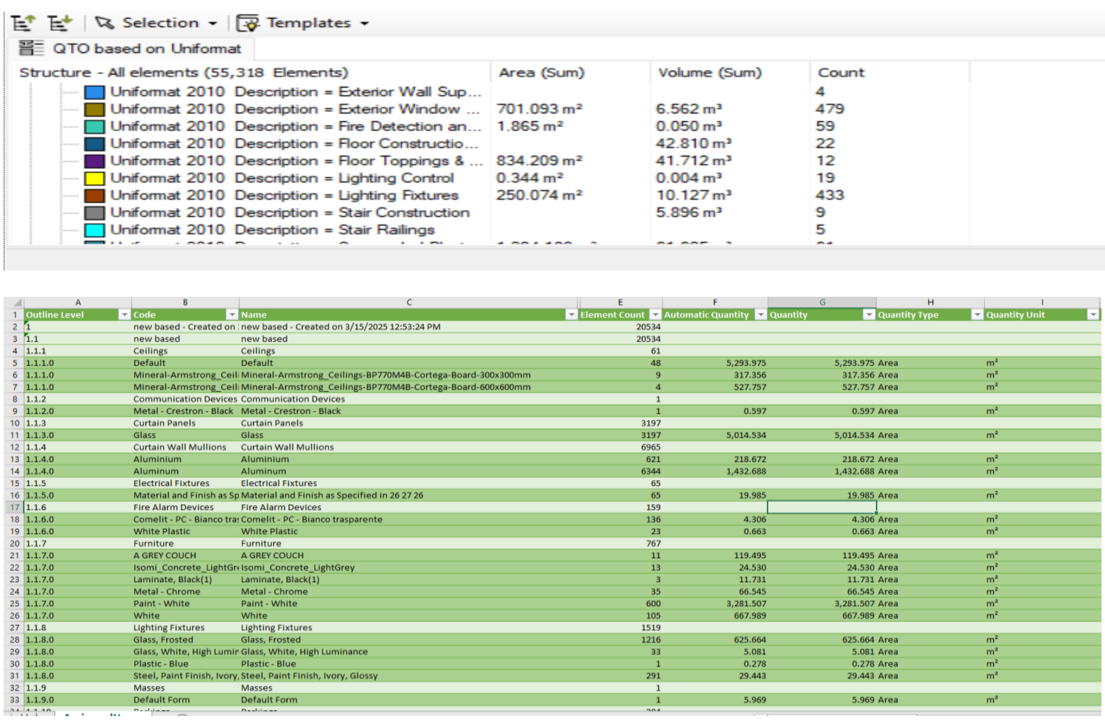
Figure 37 Grouped Elements for Quantity Takeoff of Project A

Process

Model-Based Quantification: Quantities were extracted directly from the BIM model, ensuring alignment with the design.

Custom Selection Sets: Different parts of the model were grouped into selection sets (e.g., walls, floors, beams) for targeted quantity takeoff.

Dynamic Updates: As the model evolved, QTO results were automatically updated to reflect changes.



Selection Templates

QTO based on Uniformat

Structure - All elements (55,318 Elements)	Area (Sum)	Volume (Sum)	Count
Uniformat 2010 Description = Exterior Wall Sup...			4
Uniformat 2010 Description = Exterior Window ...	701.093 m²	6.562 m³	479
Uniformat 2010 Description = Fire Detection an...	1.865 m²	0.050 m³	59
Uniformat 2010 Description = Floor Constructio...		42.810 m³	22
Uniformat 2010 Description = Floor Toppings & ...	834.209 m²	41.712 m³	12
Uniformat 2010 Description = Lighting Control	0.344 m²	0.004 m³	19
Uniformat 2010 Description = Lighting Fixtures	250.074 m²	10.127 m³	433
Uniformat 2010 Description = Stair Construction		5.896 m³	9
Uniformat 2010 Description = Stair Railings			5

	Outline Level	Code	Name	Element Count	Automatic Quantity	Quantity	Quantity Type	Quantity Unit
2	1	new based - Created on :	new based - Created on 3/15/2025 12:53:24 PM	20534				
3	1.1	new based	new based	20534				
4	1.1.1	Ceilings	Ceilings	61				
5	1.1.1.0	Default	Default	48	5,293.975	5,293.975	Area	m²
6	1.1.1.0	Mineral-Armstrong_Ceili	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-300x300mm	9	317.356	317.356	Area	m²
7	1.1.1.0	Mineral-Armstrong_Ceili	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-600x600mm	4	527.757	527.757	Area	m²
8	1.1.2	Communication Devices	Communication Devices	1				
9	1.1.2.0	Metal - Crestron - Black	Metal - Crestron - Black	1	0.597	0.597	Area	m²
10	1.1.3	Curtain Panels	Curtain Panels	3197				
11	1.1.3.0	Glass	Glass	3197	5,014.534	5,014.534	Area	m²
12	1.1.4	Curtain Wall Mullions	Curtain Wall Mullions	6965				
13	1.1.4.0	Aluminium	Aluminium	621	218.672	218.672	Area	m²
14	1.1.4.0	Aluminum	Aluminum	6344	1,432.688	1,432.688	Area	m²
15	1.1.5	Electrical Fixtures	Electrical Fixtures	65				
16	1.1.5.0	Material and Finish as Sp	Material and Finish as Specified in 26 27 26	65	19.985	19.985	Area	m²
17	1.1.6	Fire Alarm Devices	Fire Alarm Devices	159				
18	1.1.6.0	Comelit - PC - Bianco tra:	Comelit - PC - Bianco trasparente	136	4.306	4.306	Area	m²
19	1.1.6.0	White Plastic	White Plastic	23	0.663	0.663	Area	m²
20	1.1.7	Furniture	Furniture	767				
21	1.1.7.0	A GREY COUCH	A GREY COUCH	11	119.495	119.495	Area	m²
22	1.1.7.0	Isomi_Concrete_LightGr	Isomi_Concrete_LightGrey	13	24.530	24.530	Area	m²
23	1.1.7.0	Laminate, Black(1)	Laminate, Black(1)	3	11.731	11.731	Area	m²
24	1.1.7.0	Metal - Chrome	Metal - Chrome	35	66.545	66.545	Area	m²
25	1.1.7.0	Paint - White	Paint - White	600	3,281.507	3,281.507	Area	m²
26	1.1.7.0	White	White	105	667.989	667.989	Area	m²
27	1.1.8	Lighting Fixtures	Lighting Fixtures	1519				
28	1.1.8.0	Glass, Frosted	Glass, Frosted	1216	625.664	625.664	Area	m²
29	1.1.8.0	Glass, White, High Lumir	Glass, White, High Luminance	33	5.081	5.081	Area	m²
30	1.1.8.0	Plastic - Blue	Plastic - Blue	1	0.278	0.278	Area	m²
31	1.1.8.0	Steel, Paint Finish, Ivory,	Steel, Paint Finish, Ivory, Glossy	291	29.443	29.443	Area	m²
32	1.1.9	Masses	Masses	1				
33	1.1.9.0	Default Form	Default Form	1	5.969	5.969	Area	m²

Figure 38 Automated Quantity Takeoff Generation of Project A

Time Savings: Time Savings: In traditional quantity takeoff processes, the time required to manually extract and calculate quantities from construction drawings can be quite extensive. This process typically involves several steps, including reviewing plans, measuring dimensions, and compiling data into spreadsheets. For Project A, the traditional quantity takeoff took approximately 16 days, while the automated process, which included all data validation and enrichment, was completed in about 6 days. As a result, the time required for quantity takeoff was reduced by 40% due to automation replacing repetitive manual tasks.

Consistency: Dynamic updates ensured that the QTO results were always in sync with the latest model revisions.

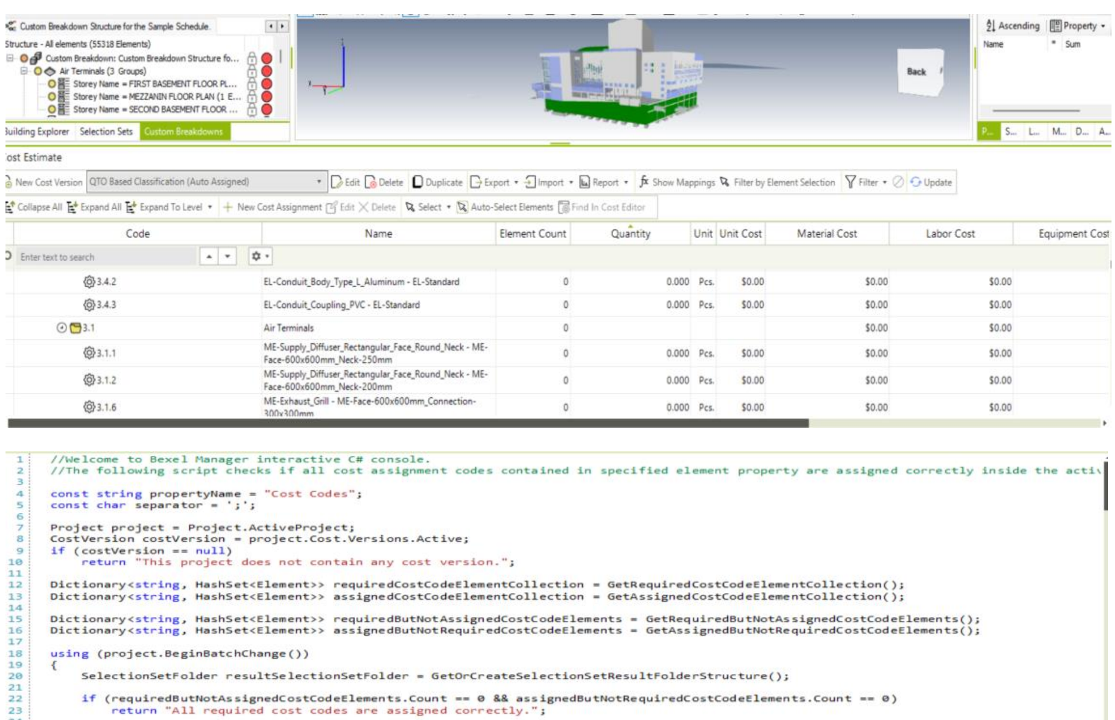
Support for Cost Estimation: The accurate quantities became the foundation for generating precise cost estimates in the 5D cost management process

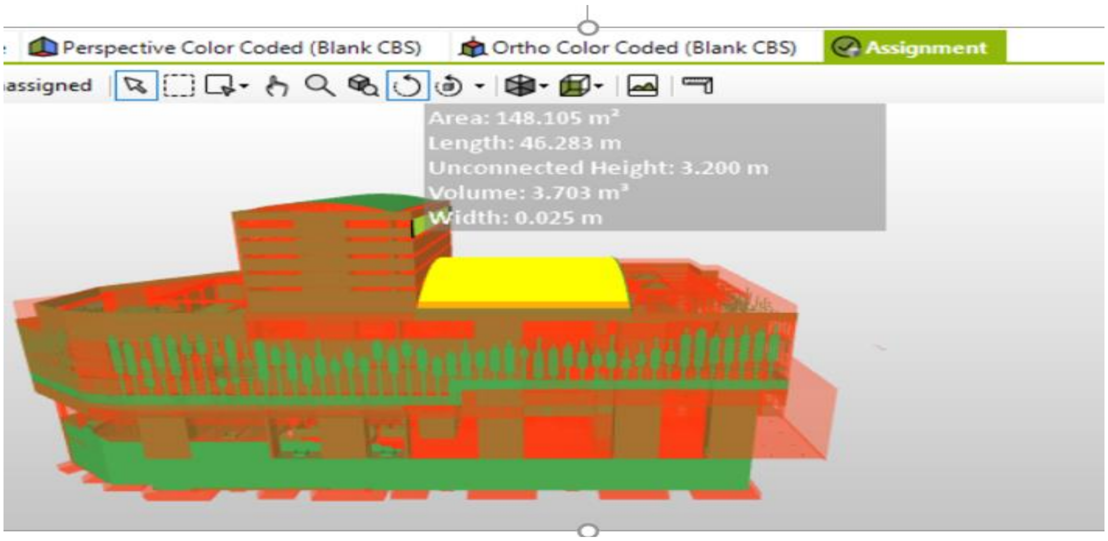
5.1.8.6 5D Cost Management

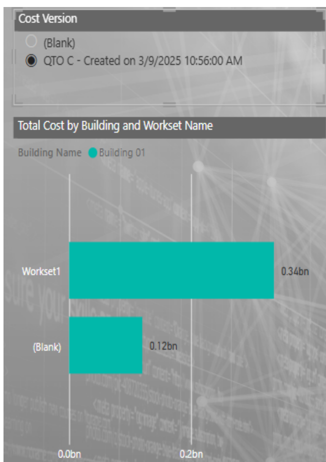
The integration of cost data into the BIM model (5D BIM) enabled real-time cost tracking and management, linking quantities and construction elements to their associated costs.

Automated Cost Item creation

Using BEXEL Manager's automated features, cost items were assigned to specific model elements based on their properties, such as material type and dimensions. **Figure 39** illustrates the detailed automated cost generation process and the results obtained from the model.







Element Properties

Building Name	Total Cost	Area	Volume	Length	Width	Number of Elements
Basic - IN_GYPSUM-PLASTERING_25MM	785,685.85	1,822.94	45.55	834.77	7.73	309
Basic - IN_HCB_150MM	198,871.14	355.13	52.99	106.37	3.15	21
Basic - EX_200-mm_HCB	197,180.14	286.60	57.15	136.25	2.80	14
Basic - SW11_30	420,714.13	179.87	53.96	50.17	3.00	10
Basic - SW7_500	345,877.46	147.87	73.94	36.97	4.00	8
Basic - IN_100-mm_DIA PARTITION WALLS	77,338.76	138.10	13.81	40.89	0.40	4
Basic - SW10_300	301,861.04	129.06	38.72	35.69	2.10	7
Basic - SW4_500	292,911.98	125.23	62.61	36.75	4.00	8
Basic - IN_HCB_200MM	83,248.71	121.00	24.20	42.91	2.00	10
Basic - IN_200-mm_DIA PARTITION WALLS 2	54,728.12	97.73	19.55	30.94	1.20	6
Basic - SW9_800	196,476.00	84.00	67.20	21.00	4.80	6
Basic - EX_25-mm_PLS-resess	24,984.31	79.82	2.00	39.28	0.03	1
Basic - IN _HCB_100MM	33,700.32	74.89	7.49	32.85	0.80	8
Total	**456,236,327.36**	**101,313.76**	**89,033.51**	**26,021.10**	**4,421.89**	**21256**

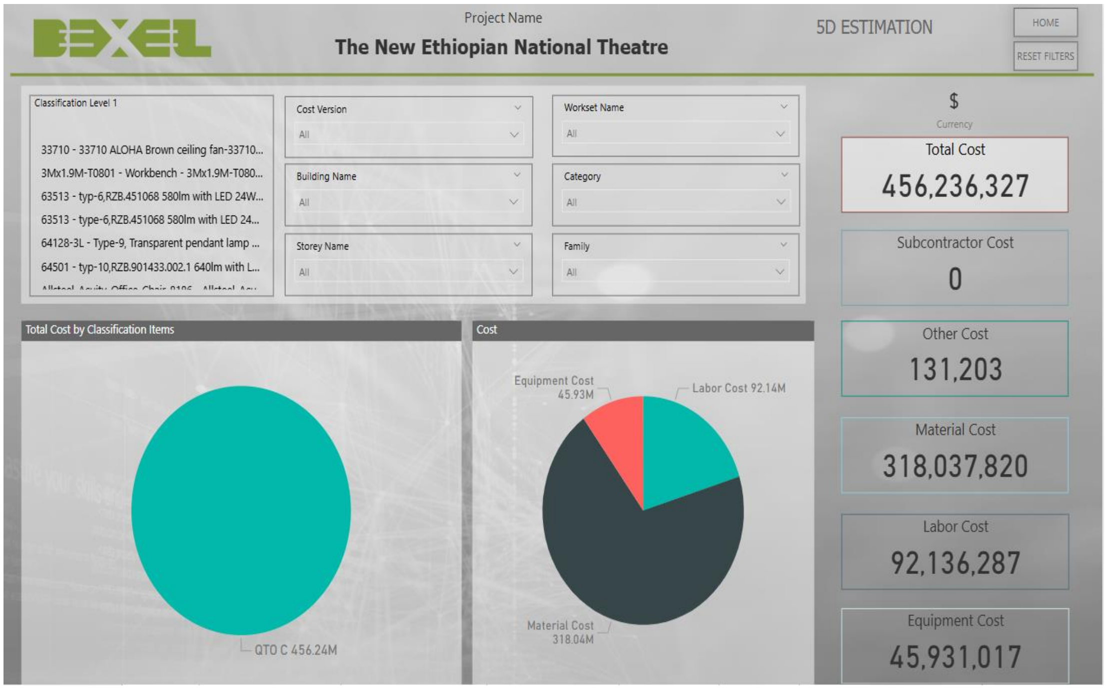
Total Cost per Classification Items

Classification

Classification	Subconstrator Cost	Other Cost	Material Cost	Labor Cost	Equipment Cost	Total Cost
⊟	0.00	0.00	375.94	107.41	53.71	537.05
⊟ HCB	0.00	0.00	375.94	107.41	53.71	537.05
QTO C - Created on 3_9_2025 10_56_00 AM.xlsx	0.00	0.00	375.94	107.41	53.71	537.05
⊟ Basic - IN_HCB_200MM-Basic - IN_HCB_200MM	0.00	0.00	752,996.87	215,141.96	107,570.98	1,075,709.81
⊟	0.00	0.00	752,996.87	215,141.96	107,570.98	1,075,709.81
⊟	0.00	0.00	752,996.87	215,141.96	107,570.98	1,075,709.81
⊟	0.00	0.00	752,996.87	215,141.96	107,570.98	1,075,709.81
⊟ Nttp_Hcb_200mm	0.00	0.00	752,996.87	215,141.96	107,570.98	1,075,709.81
QTO C - Created on 3_9_2025 10_56_00 AM.xlsx	0.00	0.00	752,996.87	215,141.96	107,570.98	1,075,709.81
⊟ Basic - IN_MARBLE TILE_600x600MM-Basic - IN_MARBLE TILE_600x600MM	0.00	0.00	1,040,636.92	297,324.83	148,662.42	1,486,624.17
⊟	0.00	0.00	1,040,636.92	297,324.83	148,662.42	1,486,624.17
Total	**0.00**	**131,203.43**	**318,037,819.77**	**92,136,287.19**	**45,931,016.97**	**456,236,327.36**

Classification

Classification	Subconstrator Cost	Other Cost	Material Cost	Labor Cost	Equipment Cost	Total Cost
QTO C - Created on 3_9_2025 10_56_00 AM.xlsx	0.00	0.00	5,488,169.04	1,568,048.30	784,024.15	7,840,241.49
⊟ Default	0.00	0.00	5,488,169.04	1,568,048.30	784,024.15	7,840,241.49
QTO C - Created on 3_9_2025 10_56_00 AM.xlsx	0.00	0.00	5,488,169.04	1,568,048.30	784,024.15	7,840,241.49
⊟ DECORATIVE-CELLING_600 x 600mm-DECORATIVE-CELLING_600 x 600mm	0.00	0.00	4,884,057.37	1,395,444.96	697,722.48	6,977,224.81
⊟	0.00	0.00	4,884,057.37	1,395,444.96	697,722.48	6,977,224.81
⊟	0.00	0.00	4,884,057.37	1,395,444.96	697,722.48	6,977,224.81
⊟	0.00	0.00	4,884,057.37	1,395,444.96	697,722.48	6,977,224.81
⊟ Nttp_Ceiling-tile_600 x 600	0.00	0.00	3,712,645.49	1,060,755.85	530,377.93	5,303,779.27
QTO C - Created on 3_9_2025 10_56_00 AM.xlsx	0.00	0.00	3,712,645.49	1,060,755.85	530,377.93	5,303,779.27
⊟ Nttp_Cement Screed	0.00	0.00	1,171,411.87	334,689.11	167,344.55	1,673,445.53
QTO C - Created on 3_9_2025 10_56_00 AM.xlsx	0.00	0.00	1,171,411.87	334,689.11	167,344.55	1,673,445.53
⊟ Dining_Table_and_Chairs_16033 - Dining_Table_and_Chairs_16033-Dining_Table_and_Chairs_16033 - Dining_Table_and_Chairs_16033	0.00	0.00	437,721.92	125,063.41	62,531.70	625,317.03
Total	**0.00**	**131,203.43**	**318,037,819.77**	**92,136,287.19**	**45,931,016.97**	**456,236,327.36**



	C	E	F	G	H	N	O	P
1	Name	Element Count	Automatic Qua	Quantity	Quantity T	Material Sup	Labor Supple	Equipment S
2	new based - Created on 3/15/2025 12:53:24 PM	20534						
3	new based	20534						
4	Ceilings	61						
5	Default	48	5,293.975	5,293.975	Area	$ 8,000.00	$ 800.00	$ 500.00
6	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-	9	317.356	317.356	Area	$ 8,000.00	$ 800.00	$ 500.00
7	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-	4	527.757	527.757	Area	$ 8,000.00	$ 800.00	$ 500.00
9	Metal - Crestron - Black	1	0.597	0.597	Area	$ 8,000.00	$ 800.00	$ 500.00
10	Curtain Panels	3197						
11	Glass	3197	5,014.534	5,014.534	Area	$ 8,000.00	$ 800.00	$ 500.00
12	Curtain Wall Mullions	6965						
13	Aluminium	621	218.672	218.672	Area	$ 8,000.00	$ 800.00	$ 500.00
14	Aluminum	6344	1,432.688	1,432.688	Area	$ 8,000.00	$ 800.00	$ 500.00
20	Furniture	767						
21	A GREY COUCH	11	119.495	119.495	Area	$ 8,000.00	$ 800.00	$ 500.00
22	Isomi_Concrete_LightGrey	13	24.530	24.530	Area	$ 8,000.00	$ 800.00	$ 500.00
23	Laminate, Black(1)	3	11.731	11.731	Area	$ 8,000.00	$ 800.00	$ 500.00
24	Metal - Chrome	35	66.545	66.545	Area	$ 8,000.00	$ 800.00	$ 500.00
25	Paint - White	600	3,281.507	3,281.507	Area	$ 8,000.00	$ 800.00	$ 500.00
26	White	105	667.989	667.989	Area	$ 8,000.00	$ 800.00	$ 500.00

Figure 39 Automated Cost Creation of Project A

Linking cost item to the model (Auto assign)

Cost items (e.g., labor, materials, equipment) were created and linked to model elements.

Process

Dynamic Cost Updates: Changes to the model, such as revised quantities, automatically triggered updates to the associated cost data.

Scenario Analysis: Different cost scenarios were simulated to evaluate the impact of design changes, schedule adjustments, or material substitutions.

Construction Costs Estimation

Classification	Subconstrator Cost	Other Cost	Material Cost	Labor Cost	Equipment Cost	Total Cost	Element Count
Armstrong Ceiling 600x600x15-Armstrong Ceiling 600x600x15	0.00	0.00	175,387.96	50,110.84	25,055.42	250,554.22	1
	0.00	0.00	175,387.96	50,110.84	25,055.42	250,554.22	1
	0.00	0.00	175,387.96	50,110.84	25,055.42	250,554.22	1
	0.00	0.00	175,387.96	50,110.84	25,055.42	250,554.22	1
Armstrong Ceiling (Parafon Hygien) 300x300x15-Armstrong Ceiling (Parafon Hygien) 300x300x15	0.00	0.00	519,606.41	148,458.97	74,229.49	742,294.87	9
	0.00	0.00	519,606.41	148,458.97	74,229.49	742,294.87	9
	0.00	0.00	519,606.41	148,458.97	74,229.49	742,294.87	9
	0.00	0.00	519,606.41	148,458.97	74,229.49	742,294.87	9
Armstrong Ceiling (Ultima) 600x600x15-Armstrong Ceiling (Ultima) 600x600x15	0.00	0.00	49,579.06	14,165.45	7,082.72	70,827.23	1
	0.00	0.00	49,579.06	14,165.45	7,082.72	70,827.23	1
	0.00	0.00	49,579.06	14,165.45	7,082.72	70,827.23	1
	0.00	0.00	49,579.06	14,165.45	7,082.72	70,827.23	1
ARMSTRONG CEILING 600 x 600mm-ARMSTRONG CEILING 600 x 600mm	0.00	0.00	3,527,872.28	1,007,963.51	503,981.75	5,039,817.54	44
Total	**0.00**	**131,203.43**	**318,037,819.77**	**92,136,287.19**	**45,931,016.97**	**456,236,327.36**	**83288**

Construction Costs Estimation

Classification	Subconstrator Cost	Other Cost	Material Cost	Labor Cost	Equipment Cost	Total Cost	Element Count
	0.00	0.00	38,309.68	10,945.62	5,472.81	54,728.12	6
	0.00	0.00	38,309.68	10,945.62	5,472.81	54,728.12	6
Basic - IN_GYPSUM-PLASTERING_25MM-Basic - IN_GYPSUM-PLASTERING_25MM	0.00	0.00	3,293,947.30	941,127.80	470,563.90	4,705,639.00	2197
	0.00	0.00	3,293,947.30	941,127.80	470,563.90	4,705,639.00	2197
	0.00	0.00	3,293,947.30	941,127.80	470,563.90	4,705,639.00	2197
	0.00	0.00	3,293,947.30	941,127.80	470,563.90	4,705,639.00	2197
Basic - IN_HCB_150-mm_FOR FILL_126MM-Basic - IN_HCB_150-mm_FOR FILL_126MM	0.00	0.00	1,397.93	399.41	199.70	1,997.05	2
	0.00	0.00	1,397.93	399.41	199.70	1,997.05	2
	0.00	0.00	1,397.93	399.41	199.70	1,997.05	2
	0.00	0.00	1,397.93	399.41	199.70	1,997.05	2
Basic - IN_HCB_150-mm_FOR FILL-Basic - IN_HCB_150-mm_FOR FILL	0.00	0.00	1,350.25	385.79	192.89	1,928.93	2
	0.00	0.00	1,350.25	385.79	192.89	1,928.93	2
	0.00	0.00	1,350.25	385.79	192.89	1,928.93	2
	0.00	0.00	1,350.25	385.79	192.89	1,928.93	2
Total	**0.00**	**131,203.43**	**318,037,819.77**	**92,136,287.19**	**45,931,016.97**	**456,236,327.36**	**83288**

Code	Description	Element Count	Automatic	Quantity	Quantity	Quantity Ur	Quantity	Automatic	Unit Cost	Total Cost	Other Cost	Subcontractor Cost	Material Suppleme	Labor Suppleme	Equipment Suppleme	Class
Uniformat (Auto-assigne		10857								$ 7,935,753.57	$ 0.00	$ 0.00	$ 3,494,452.49	$ 37,840.71	$ 39,504.66	
Uniformat		10857								$ 7,935,753.57	$ 0.00	$ 0.00	$ 3,494,452.49	$ 37,840.71	$ 39,504.66	
A		315								$ 714,266.70	$ 0.00	$ 0.00	$ 355,323.34	$ 0.00	$ 0.00	
A10		315								$ 714,266.70	$ 0.00	$ 0.00	$ 355,323.34	$ 0.00	$ 0.00	
A1010		294								$ 531,499.82	$ 0.00	$ 0.00	$ 267,254.31	$ 0.00	$ 0.00	
A1010130		294								$ 531,499.82	$ 0.00	$ 0.00	$ 267,254.31	$ 0.00	$ 0.00	
A10101300001		48								$ 44,272.32	$ 0.00	$ 0.00	$ 16,047.38	$ 0.00	$ 0.00	
03 11 1345 0001	C.I.P. concrete forms, pile cap, square or rectangular, plywood, 4 use, includes erecting, bracing, stripping and cleaning	48	224.640	224.640	Area	m²	2*([Widtl	$ 82.57	$ 82.57	$ 18,547.53	$ 0.00	$ 0.00	$ 2,340.52	$ 0.00	$ 0.00	4648t
03 21 1060 0000	Reinforcing steel, in place, footings, #8 to #18, A615, grade 60, incl labor for accessories, excl material for accessories	48	########	########	Mass	kg	[Volume]'	$ 3.13	$ 3.13	$ 10,487.23	$ 0.00	$ 0.00	$ 3,263.16	$ 0.00	$ 0.00	4648t
03 31 0535 0007	Structural concrete, ready mix, normal weight, 20.00Mpa, includes local aggregate, sand, portland cement and water, excludes all	48	63.452	63.452	Volume	m³	[Volume]	$ 164.59	$ 164.59	$ 10,443.70	$ 0.00	$ 0.00	$ 10,443.70	$ 0.00	$ 0.00	4648t
03 31 0570 0001	Structural concrete, placing, pile caps, direct chute, under 3.83m3, includes vibrating, excludes material	48	63.452	63.452	Volume	m³	[Volume]	$ 56.70	$ 56.70	$ 3,597.65	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$ 0.00	4648t
31 23 1642 0000	Excavating, bulk bank measure, 0.38m3 = 22.94m3/hour, hydraulec	48	63.452	63.452	Volume	m³	[Volume]	$ 18.85	$ 18.85	$ 1,196.21	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$ 0.00	4648t
A10101300002		30								$ 66,100.51	$ 0.00	$ 0.00	$ 27,968.11	$ 0.00	$ 0.00	
03 11 1345 0001	C.I.P. concrete forms, pile cap, square or rectangular, plywood, 4 use, includes erecting, bracing, stripping and cleaning	30	216.000	216.000	Area	m²	2*([Widtl	$ 82.57	$ 82.57	$ 17,834.17	$ 0.00	$ 0.00	$ 2,250.50	$ 0.00	$ 0.00	4648t
03 21 1060 0000	Reinforcing steel, in place, footings, #8 to #18, A615, grade 60, incl labor for accessories, excl material for accessories	30	########	########	Mass	kg	[Volume]'	$ 3.13	$ 3.13	$ 19,676.75	$ 0.00	$ 0.00	$ 6,122.53	$ 0.00	$ 0.00	4648t
03 31 0535 0007	Structural concrete, ready mix, normal weight, 20.00Mpa, includes local aggregate, sand, portland cement and water, excludes all	30	119.052	119.052	Volume	m³	[Volume]	$ 164.59	$ 164.59	$ 19,595.07	$ 0.00	$ 0.00	$ 19,595.07	$ 0.00	$ 0.00	4648t
03 31 0570 0001	Structural concrete, placing, pile caps, direct chute, under 3.83m3, includes vibrating, excludes material	30	119.052	119.052	Volume	m³	[Volume]	$ 56.70	$ 56.70	$ 6,750.12	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$ 0.00	4648t
31 23 1642 0000	Excavating, bulk bank measure, 0.38m3 = 22.94m3/hour, hydraulec	30	119.052	119.052	Volume	m³	[Volume]	$ 18.85	$ 18.85	$ 2,244.40	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$ 0.00	4648t
A10101300003		96								$ 178,136.42	$ 0.00	$ 0.00	$ 87,409.31	$ 0.00	$ 0.00	

Figure 40 Linking Cost Item to the Model (Auto Assign Process) for Project A

Results

Real-Time Cost Tracking: The project team could monitor costs dynamically as the model evolved, ensuring transparency and better budget control.

Improved Budget Accuracy: Linking costs to model elements reduced the risk of budget overruns by providing a detailed and accurate breakdown of expenses.

Value Engineering: The ability to simulate cost scenarios allowed the team to optimize designs and select cost-efficient materials and methods.

Cost Savings: The implementation of BEXEL Manager has been shown to contribute to overall project savings. This reduction in costs is primarily driven by two key factors: reduced errors and optimized resource allocation. However, to accurately state the exact savings, it is essential to calculate the Return on Investment (ROI), as there are initial costs associated with the BIM implementation plan.

5.1.8.7 4D/5D Construction planning

Construction planning (4D BIM) and cost management (5D BIM) were integrated into the project, enabling the creation of optimized schedules that accounted for time, resources, and costs. BEXEL Manager provided advanced tools for creating, analyzing, and optimizing construction schedules.

Creating a Construction Schedule

Predefined Selection Sets: The construction schedule was built using predefined selection sets (e.g., specific building components such as floors, walls, or zones).

Zones and Methodologies: The project was divided into zones (e.g., parking areas, auditorium, office tower) to prioritize tasks and improve workflow efficiency.

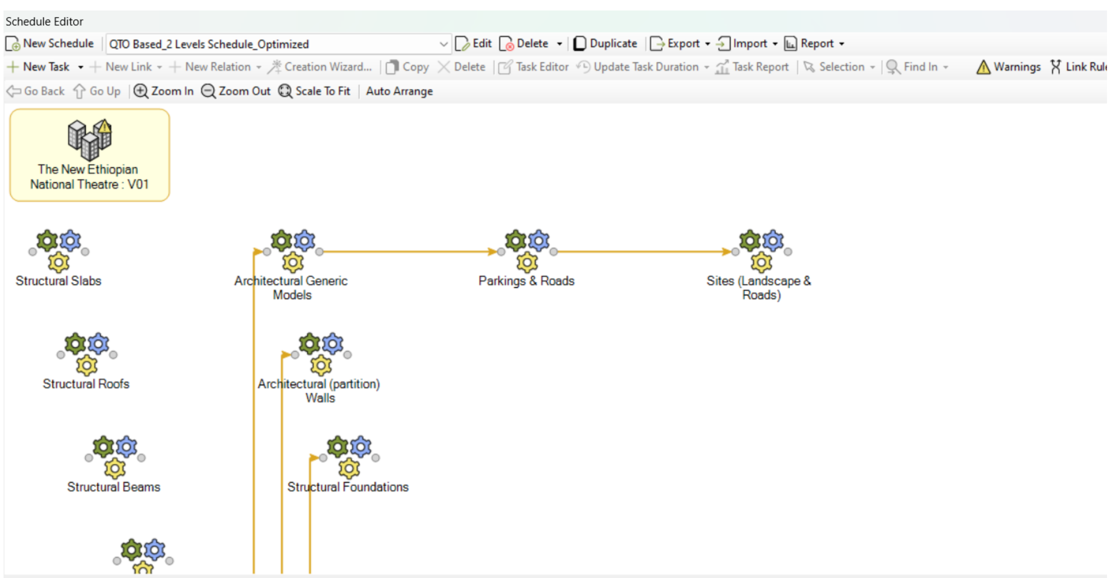


Figure 41 Creating Zones and Methodology for project A

Linking Tasks to Model Elements: Each task in the schedule was linked to the corresponding BIM elements, ensuring that progress tracking and updates were directly tied to the model.

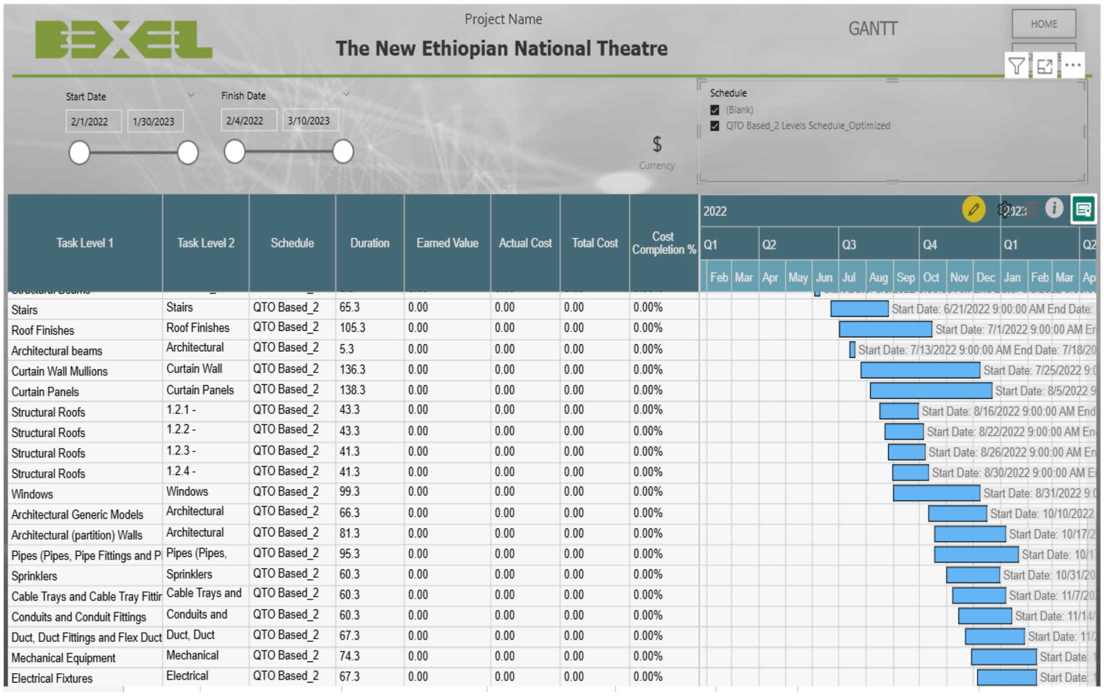


Figure 42 Linking Tasks to the Model Element of Project A

Results:

Clearer Construction Phases: Breaking the project into zones provided better visibility into task dependencies and priorities.

Accurate Task Assignments: Linking tasks to model elements ensured that resources and labor were allocated appropriately.

5.1.8.8 Schedule Optimization

Schedule optimization in construction offers several key advantages, including improved project efficiency by minimizing delays and ensuring tasks are completed on time. It enhances resource allocation, ensuring labor, materials, and equipment are used effectively to avoid waste. Optimized schedules also improve coordination between teams, reducing conflicts and bottlenecks during execution.

Schedule Optimization Using Line of Balance (LOB)

The Line of Balance (LOB) method was employed to optimize the construction sequence by balancing resource allocation and task durations.

Results:

Minimized Idle Time: LOB minimized resource downtime by ensuring that tasks were executed in a logical and continuous sequence.

Improved Resource Utilization: Labor and equipment were allocated more efficiently, reducing waste and delays.

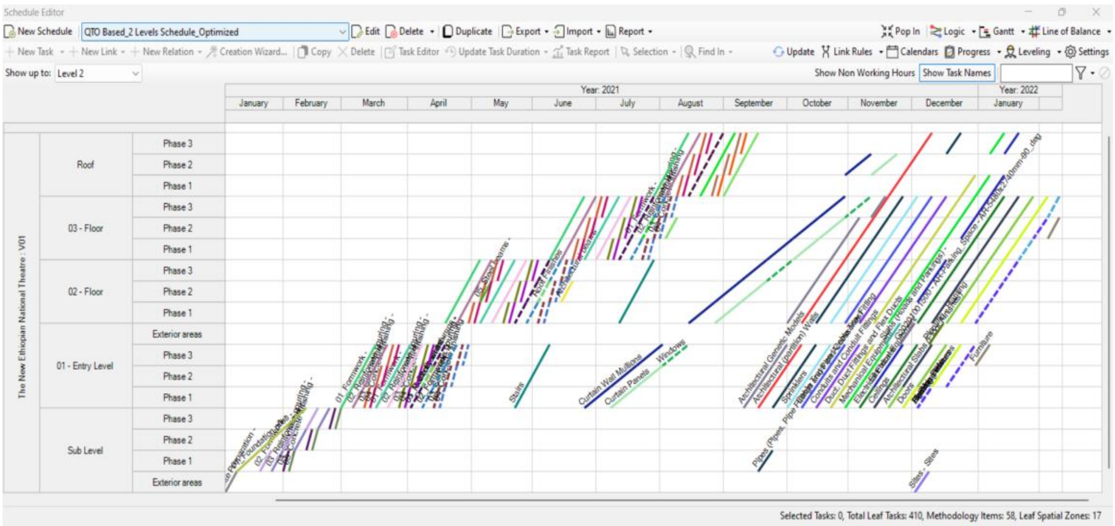


Figure 43 Schedule Optimization Using LOB for Project A

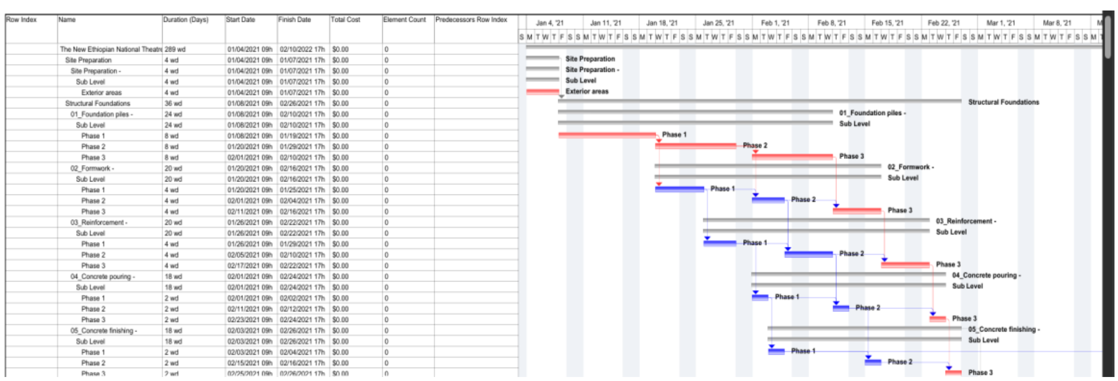


Figure 44 Optimized Schedule Using LOB for Project A

Schedule Optimization Using Automatic Task Duration Calculation

Task durations were calculated automatically based on quantities, productivity rates, and resource availability.

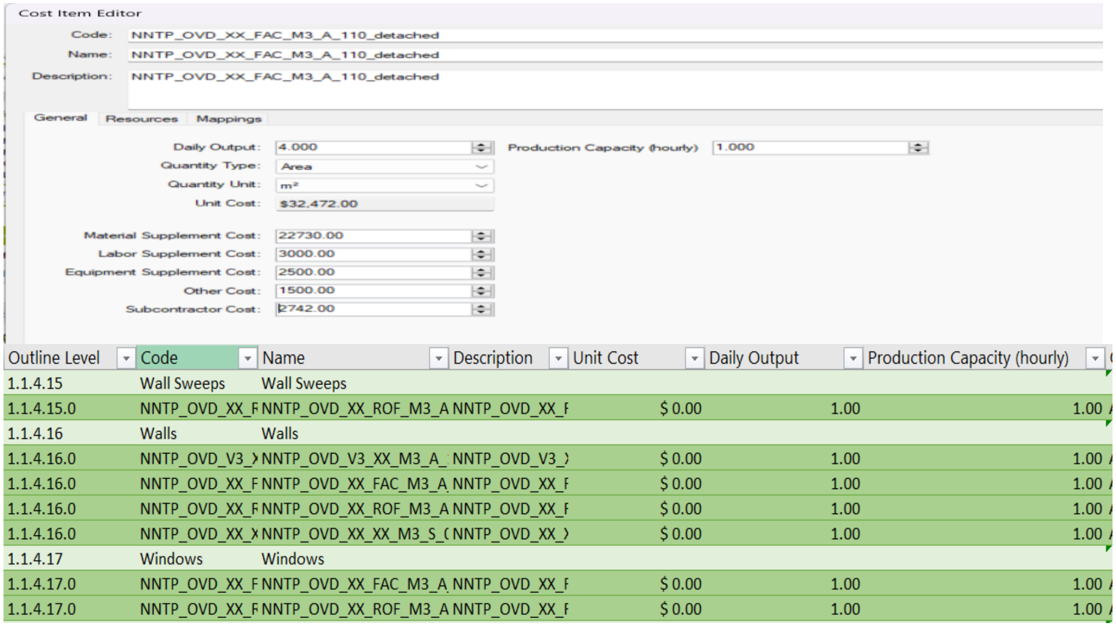


Figure 45 Automatic Task Duration calculation for Schedule Optimization of Project A

Results:

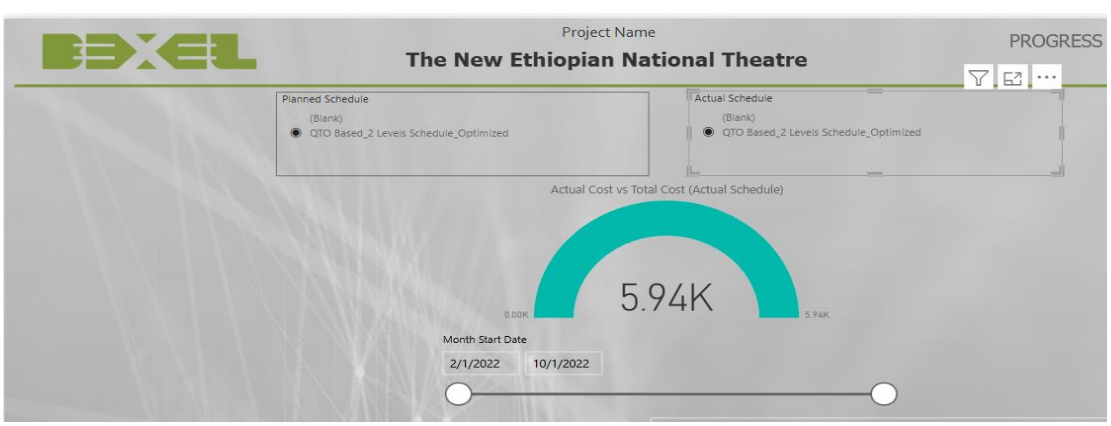
Realistic Timelines: Automatically calculated durations aligned with actual site conditions, reducing the risk of delays caused by unrealistic schedules.

Increased Efficiency: Automation eliminated the need for manual duration calculations, saving time and improving accuracy.

5.1.8.9 Reporting and Analytics

Weekly Report

Weekly reports and analytics were generated from BEXEL Manager to monitor project progress and performance.



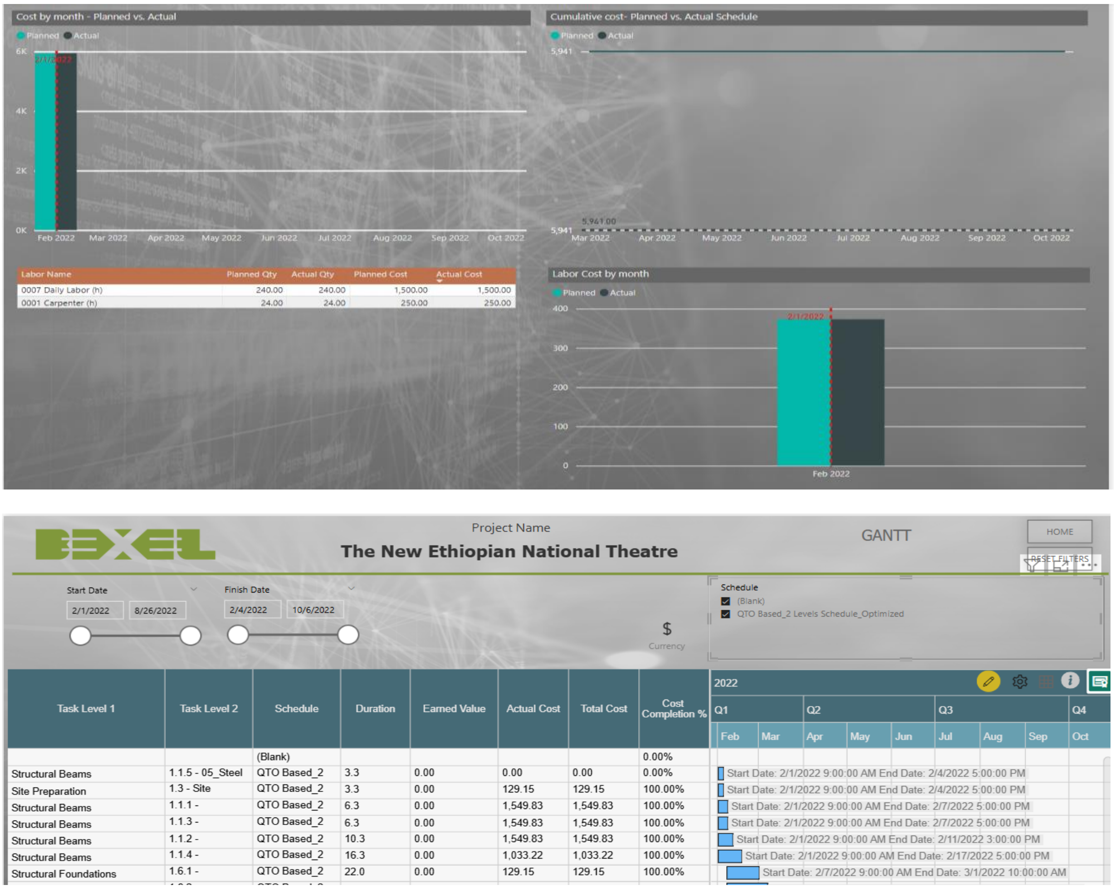


Figure 46 Weekly Generated Reports for Project A

Results:

Enhanced Transparency: Stakeholders received regular updates on progress, costs, and schedules, fostering trust and accountability.

Data-Driven Decisions: Analytics provided insights into critical project aspects, enabling proactive risk management and better decision-making.

5.1.8.10 Progress Monitoring

Progress monitoring is a critical component of the BIM-based project management workflow. By integrating progress tracking into BIM, the New Ethiopian National Theater Project leveraged real-time data to evaluate the alignment between planned and actual project performance. This approach enabled proactive decision-making and ensured project milestones were met efficiently.

Implementation Process

Integration of Progress Data into BIM

- Progress monitoring was conducted by linking the construction schedule (4D/5D BIM) to the BIM model within BEXEL Manager.
- Regular site updates, including completed tasks, resource utilization, and material deliveries, were fed into the BIM model to track actual progress.

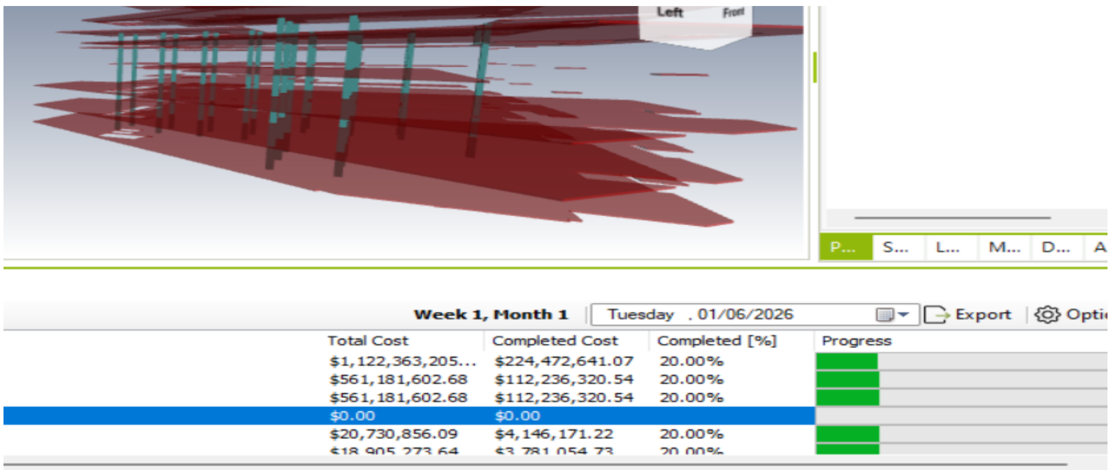


Figure 47 Integration of Progress Data in to BIM for Project A

Visual Progress Tracking

- The BIM model was used to visually represent the progress of construction tasks.
- Completed construction elements were color-coded within the model, providing a clear visual representation of what had been built versus what remained.

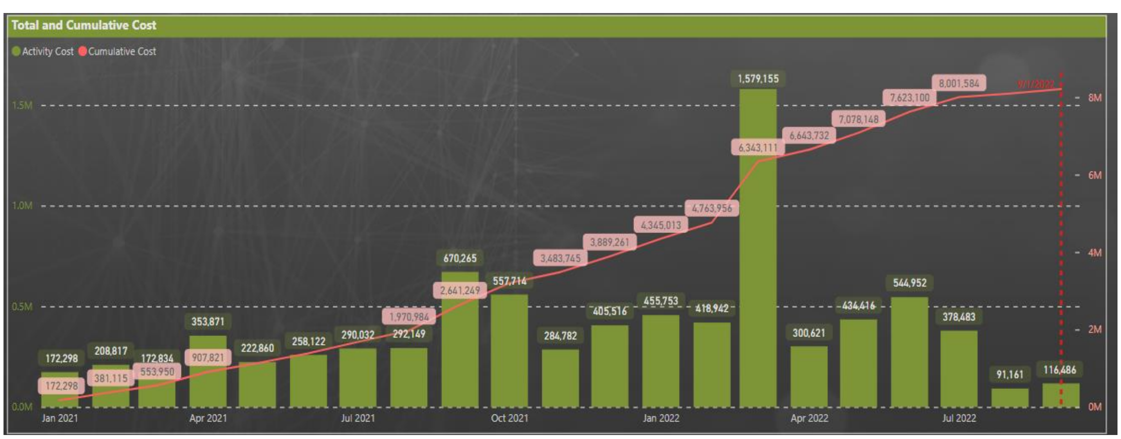


Figure 48 Visual Progress Tracking

Comparison of Planned vs. Actual Progress

- Data from the updated model was compared against the planned schedule to identify deviations or delays.
- Variances were flagged for further analysis, and corrective actions were implemented to bring the project back on track.

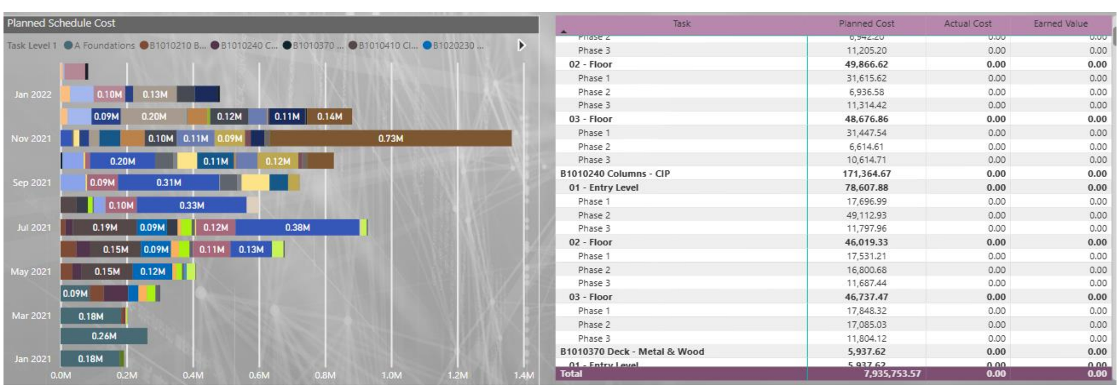


Figure 49 Earned Value Management for Project A

Data Collection and Integration

- Data was collected from the site using digital tools and field reports.
- Field updates were integrated into the BIM model through the Common Data Environment (CDE) platform, ensuring consistency and accuracy.

Figure 50 Data Integration for Progress Monitoring of Project A

Results

Enhanced Visibility: Real-time progress updates provided project stakeholders with a clear understanding of the construction status, enhancing transparency and collaboration.

Proactive Risk Management: Early identification of delays or resource bottlenecks allowed the project team to implement corrective measures promptly.

Improved Communication: Visual progress reports facilitated better communication between site teams, project managers, and stakeholders.

Time Management: Progress tracking ensured that tasks were completed on schedule, reducing the risk of delays in subsequent phases.

During the construction of the auditorium**,** progress monitoring revealed a delay in the installation of structural steel components due to unresolved clashes. This delay was flagged in the BIM model, prompting the team to adjust the schedule and prioritize other tasks in parallel, minimizing the overall impact on the project timeline.

5.1.8.11 Scheduling Simulation

Scheduling simulation is a key feature of 4D BIM, allowing project stakeholders to visualize and optimize construction sequences before actual site implementation. For the New Ethiopian National Theater Project, scheduling simulations were conducted using BEXEL Manager to analyze construction workflows, identify inefficiencies, and optimize resource allocation.

Implementation Process

Creation of the Federated 4D Model

- A federated BIM model was linked to the construction schedule in BEXEL Manager, creating a 4D simulation of the project.
- Tasks in the schedule were directly tied to model elements, ensuring alignment between the timeline and the physical components of the building.

Simulation of Construction Sequences

- The scheduling simulation visualized the step-by-step progression of construction activities, displaying the timing and sequence of tasks in a 3D environment.
- Various scenarios were simulated to evaluate the impact of different construction methodologies or resource allocation strategies.

Adjustments Based on Simulation Insights

- Inefficiencies or conflicts identified during the simulation were addressed by adjusting the schedule or re-sequencing tasks.
- Simulations were iteratively refined to optimize the timeline and ensure smooth workflows.

Resource and Zone-Based Planning

- The project was divided into zones (e.g., parking, auditorium, office tower) for detailed resource planning.
- Simulations were used to allocate resources (labor, equipment, materials) to specific zones, ensuring balanced workloads and minimizing idle time.

Results

Improved Construction Sequencing: Simulations revealed potential task overlaps and bottlenecks, allowing the team to resequencing activities for efficiency.

Optimized Resource Utilization: Resources were allocated more effectively, reducing idle time and ensuring that labor and equipment were used to their full potential.

Risk Mitigation: By visualizing potential conflicts or delays in advance, the project team was able to mitigate risks before they occurred on-site.

Stakeholder Engagement: The simulations provided stakeholders with an intuitive understanding of the construction process, improving communication and decision-making.

5.2 BIM Maturity Assessment: Interview Insights with the BIM Manager of Project A

In the context of the New Ethiopian National Theater Project, a comprehensive BIM Maturity Assessment was conducted to evaluate the current state of BIM adoption and its alignment with the project's target maturity level. During an interview with the BIM Manager, detailed insights were gathered on the project's existing capabilities, challenges, and areas requiring improvement. The results have been visualized and analyzed using a spider radar chart and scoring matrix, as outlined below.

1. Current vs Target BIM Maturity Radar

The BIM Maturity Radar compares the current state of the project's BIM implementation against its desired target state. The radar chart highlights key categories such as Leadership & Management, BIM Vision, Technology Infrastructure, and Collaboration, among others. These categories are evaluated on a scale from 0 to 1 for radar visualization and 0 to 4 for detailed scoring.

BIM Manager's Key Observations

- The current BIM maturity is at a "Managed" (Level 2) stage, indicating that defined processes are in place, but there is room for standardization and optimization.
- The target BIM maturity is at a "Defined/Integrated" (Level 3) stage, emphasizing the need for structured workflows, enhanced collaboration, and optimized processes to maximize the benefits of BIM adoption.

Radar Chart Key Insights

The BIM Maturity Radar categorizes efforts into four quadrants:

Target State: Desired maturity goals for key categories.

Current Strengths: Areas where the project is performing relatively well.

Improvement Areas: Categories requiring incremental improvements.

Development Needs: Key focus areas with significant gaps to achieve target maturity.

The following performance scores for the categories were discussed with the BIM Manager:

Table 5-4 BIM Maturity Performance Score

Category	Current Score	Target Score	Gap
Leadership & Management	2.6	3.5	0.9
BIM Vision	2.4	3.4	1
Technology Infrastructure	2.8	3.6	0.8
Standards & Procedures	2.6	3.4	0.8
Process Management	2.2	3.2	1
Skills & Training	2	3	1
Collaboration	2.4	3.4	1
Data Management	2.2	3.2	1

2. **Strengths and Achievements**

The interview highlighted Technology Infrastructure, Leadership & Management, and Standards & Procedures as the strongest areas of current BIM maturity.

Key Strengths Identified by the BIM Manager:

- ❖ **Technology Infrastructure (Score: 2.8/4)**
  - The project has implemented advanced tools like BEXEL Manager for model coordination, clash detection, and scheduling simulations.
  - The use of a Common Data Environment (CDE) ensures seamless data sharing and collaboration.
  - High interoperability is achieved through the use of IFC (Industry Foundation Classes) and BCF (BIM Collaboration Format) standards.
- ❖ **Leadership & Management (Score: 2.6/4)**

- The project benefits from strong leadership support for BIM implementation.
- A BIM Execution Plan (BEP) has been established to guide processes and ensure compliance with ISO 19650 standards.
- Dedicated roles, such as a Project BIM Manager and BIM Coordinators, ensure accountability and oversight.

❖ **Standards & Procedures (Score: 2.6/4)**

- Clear file naming conventions, metadata requirements, and model validation processes are in place.
- Managed workflows ensure discipline-specific teams adhere to consistent standards, improving collaboration and reducing errors.

3. Areas for Improvement

The BIM Manager identified Skills & Training, Process Management, and Data Management as the most critical areas requiring improvement.

Challenges Highlighted:

❖ **Skills & Training (Score: 2.0/4)**

Gap: There is a shortage of skilled professionals with advanced BIM capabilities.

Observation: While basic BIM tools are used effectively, there is a lack of expertise in advanced techniques such as automated data enrichment, 5D cost management, and progress monitoring.

Plan: Implement targeted training programs for project teams to build knowledge in advanced BIM workflows.

❖ **Process Management (Score: 2.2/4)**

Gap: The maturity of BIM processes is limited by inconsistencies in workflow optimization.

Observation: While processes are defined, they are not yet optimized for automation and integration across all disciplines.

Plan: Develop a more robust framework for consistent process management, including clear task sequences and automated workflows.

❖ **Data Management (Score: 2.2/4)**

Gap: Inadequate systems for managing large volumes of BIM data dynamically.

Observation: Metadata inconsistencies and difficulties in tracking changes across models were noted.

Plan: Invest in advanced data management tools and implement stricter quality control mechanisms.

- ❖ **Largest Gaps to Target Maturity**

The radar analysis revealed that the largest gaps to achieve the target maturity level exist in BIM Vision, Process Management, and Skills & Training, each with a gap of 1.0.

Key Insights from the BIM Manager:

- ❖ **BIM Vision (Gap: 1.0)**

Challenge: There is a need for a more unified and long-term vision for BIM adoption within the organization.

Action: Align leadership and stakeholders on the broader benefits of BIM beyond the scope of the current project, including its potential for asset management and lifecycle optimization.

- ❖ **Process Management (Gap: 1.0)**

Challenge: Processes are not yet fully automated or standardized.

Action: Focus on automating repeatable workflows, such as data validation and quantity takeoff, to reduce manual effort and improve efficiency.

- ❖ **Skills & Training (Gap: 1.0)**

Challenge: The team lacks advanced training in areas like 5D cost management, 4D scheduling simulations, and progress monitoring.

Action: Develop a comprehensive training program for project teams, focusing on advanced BIM concepts and tools.

4. **BIM Maturity Interpretation**

The BIM Manager contextualized the maturity assessment within the broader framework of the BIM maturity levels:

Table 5-5 BIM Maturity Interpretation

Score Range	Maturity Level	Description
0.0 - 1.0	Level 0	Ad-hoc/Initial (Non-existent processes)
1.1 - 2.0	Level 1	Defined (Processes are documented but basic)
2.1 - 3.0	Level 2	Managed (Processes exist but need refinement)
3.1 - 3.5	Level 3	Integrated (Processes are standardized)
3.6 - 4.0	Level 4	Optimized (Processes are automated and efficient)

- ❖ **Current Maturity Level:**

The New Ethiopian National Theater Project is currently positioned at Level 2 (Managed), indicating that processes are defined but require further refinement.

- **Target Maturity Level:**

The project aims to achieve Level 3 (Integrated), where processes are standardized, collaboration is seamless, and workflows are highly efficient.

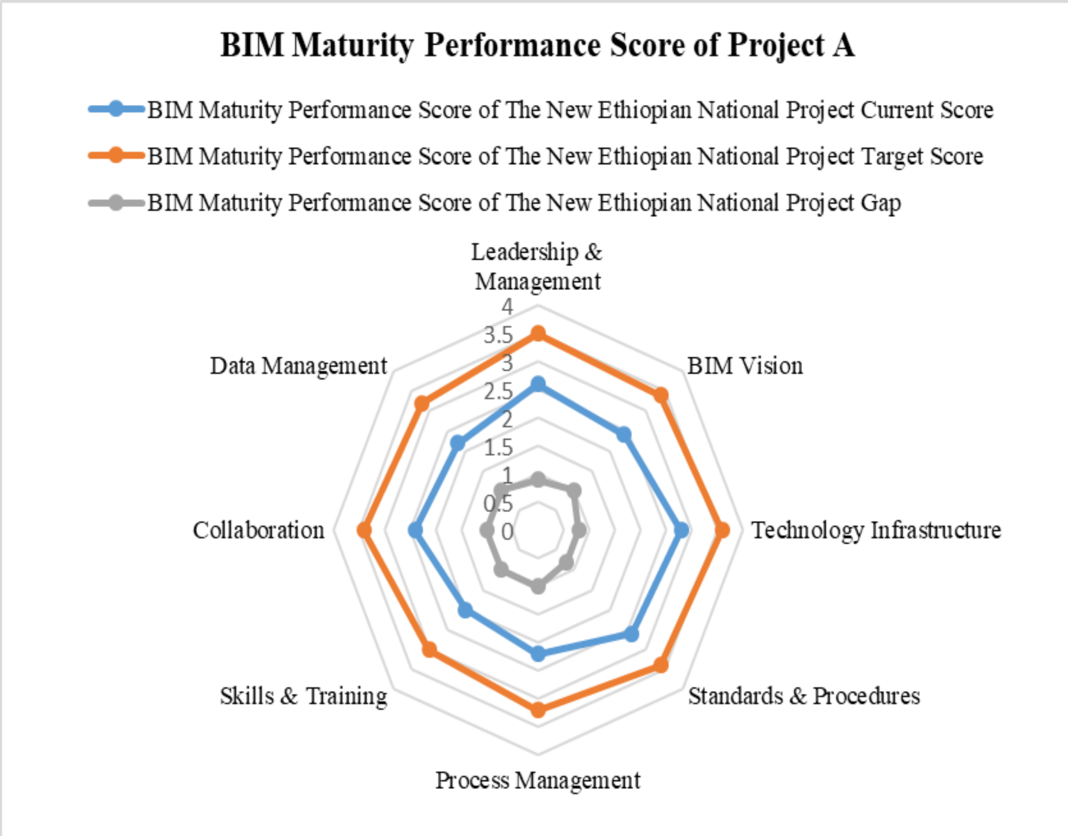


Figure 51 BIM Maturity Assessment for Project A

The BIM Maturity Assessment provided a clear roadmap for enhancing BIM implementation on the New Ethiopian National Theater Project. Strengths in technology infrastructure and leadership offer a solid foundation, but areas such as skills development, process optimization, and data management require focused efforts. By addressing these gaps, the project can achieve its target maturity level, setting a benchmark for BIM adoption in large-scale public infrastructure projects.

5.3 4D/5D BIM Implementation on Project B: Addis Capital Goods Mixed-Use Building

Project Overview: A 2B+G+10 mixed-use building with a contract amount of 1 billion birr.

Project Timeline

- Start Date: December 2022
- Expected Completion: March 2026

Location of the project: Piassa, Addis Ababa

5.3.1 BIM Objectives and Use Cases

BIM Objectives

The implementation of BIM for Company B primarily focuses on achieving a clash-free 3D BIM design, constrained to Level of Development (LOD) 200. The project's goals include minimizing errors, maintaining consistency across design disciplines, and enhancing overall design quality.

BIM Use Cases

To fulfill these objectives, specific BIM use cases were identified and implemented, limited to the 3D BIM design stage. This includes the creation of clash-free working drawings for the construction team.

5.3.2 BIM Management

Roles and Responsibilities

In Company B, the Design Department is responsible for BIM implementation at the 3D level, led by the Design Department Manager/BIM Manager, with a team of BIM Modelers. There is no separate BIM structure or specifically defined roles dedicated to BIM.

5.3.3 BIM Maturity

Insights from interviews with the Design Department Manager/BIM Manager indicate that the project adheres to Level 2 BIM, emphasizing shared models, interoperability through IFC standards, and a centralized Common Data Environment (CDE) for collaboration.

5.3.4 BIM Software and Tools

Table 5-6 Software Schedule for Project B presents the selected software utilized by the company. While the company initially planned to use Autodesk Navisworks for 4D and 5D modeling, BEXEL Manager was adopted for this study

Table 5-6 Software Schedule for Project B

Table SOFTWARE SCHEDULE

No.	Task team	Task	Software	Native format	Exchange format
1	Project-BIM management	Discipline Coordination		*.NWD, .NWC	*.IFC *.PDF
		CDE management/local server	serve based		
2	Architectural	Modeling	Autodesk Revit	*.RVT	*.IFC *.PDF
3	Structural /Civil	Modeling Structural	Autodesk Revit	*.RVT	*.IFC *.PDF
4	MEP	Electrical Modeling	Autodesk Revit	*.RVT	*.IFC *.PDF
		Mechanical Modeling	Autodesk Revit	*.RVT	*.IFC *.PDF
		Sanitary and plumbing modeling	Autodesk Revit	*.RVT	*.IFC *.PDF
		Digital Fabrication	Autodesk-CamCAD	*.CAD	*.IFC *.PDF
5	Project Management	4D/5D modeling	Autodesk-Naviswork	*.NWD	*.IFC *.PDF

5.3.5 Common Data Environment (CDE)

The project uses the local server for collaboration and data sharing. Key features include:

- Upload and approval of 3D/2D deliverables.
- Documentation traceability and decision management.

5.3.6 Quality Control and Clash Detection

Clash Detection: Conducted using Autodesk Naviswork.

5.3.7 4D/5D BIM Process: The Implementation

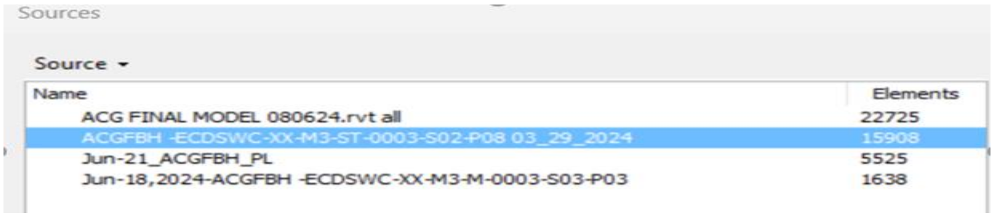


Figure 52 Federated BIM Revit Models for Project B

General Project Information

The Project

Figure 53 provides a visual representation of the project, featuring front, back, left, right, and top views.

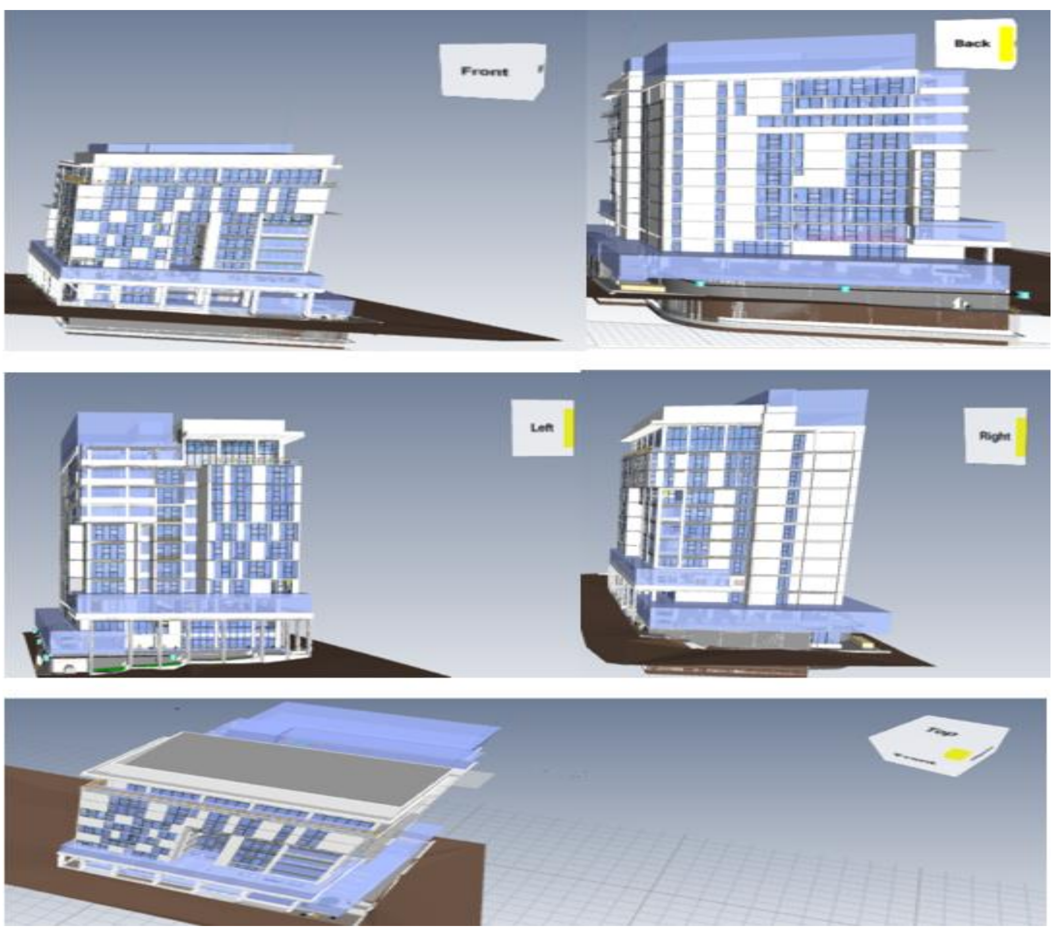


Figure 53 3D Model View of Project B

5.3.7.1 Model Data Management

Initial Model Review

The Initial Model Review conducted in BEXEL Manager provided insights into model sources, organization, accuracy, and level of detail (LOD).

Key Findings:

Model Sources: Federated models were successfully imported from Revit, with all geometry and metadata intact.

Model Organization: The source models (AR, ST, and MEP) have different work planes, resulting in duplicated stories when linked in Revit and exported as IFC files for subsequent use in BEXEL Manager. As illustrated in **Figure 54**, this discrepancy leads to an excess of the intended 15 floors, with over 90 stories present.

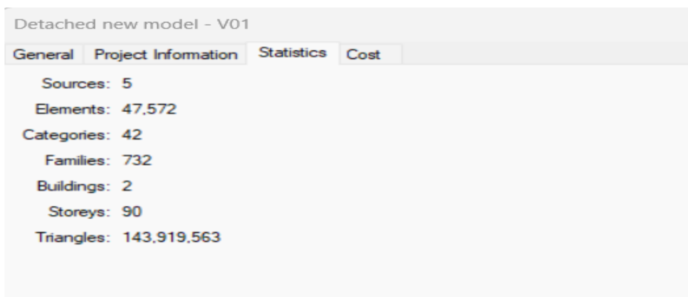


Figure 54 Model Sources and organization of Project B

Result:

- **Inaccurate Data Integration:** The misalignment of work planes and duplicated stories complicates the integration of architectural (AR), structural (ST), and MEP models. This misalignment disrupts the spatial and geometric accuracy required for 4D/5D processes.
- **Scheduling Errors:** Duplicated floors result in incorrect story data, which can lead to errors in construction sequencing (4D BIM).
- **Cost Estimation Inaccuracies:** Duplicated elements inflate material quantities and associated costs, leading to unreliable cost estimation (5D BIM).

Visual Inspection: **Figure 55** demonstrate the offset elements showing components displaced above or below their intended floors.

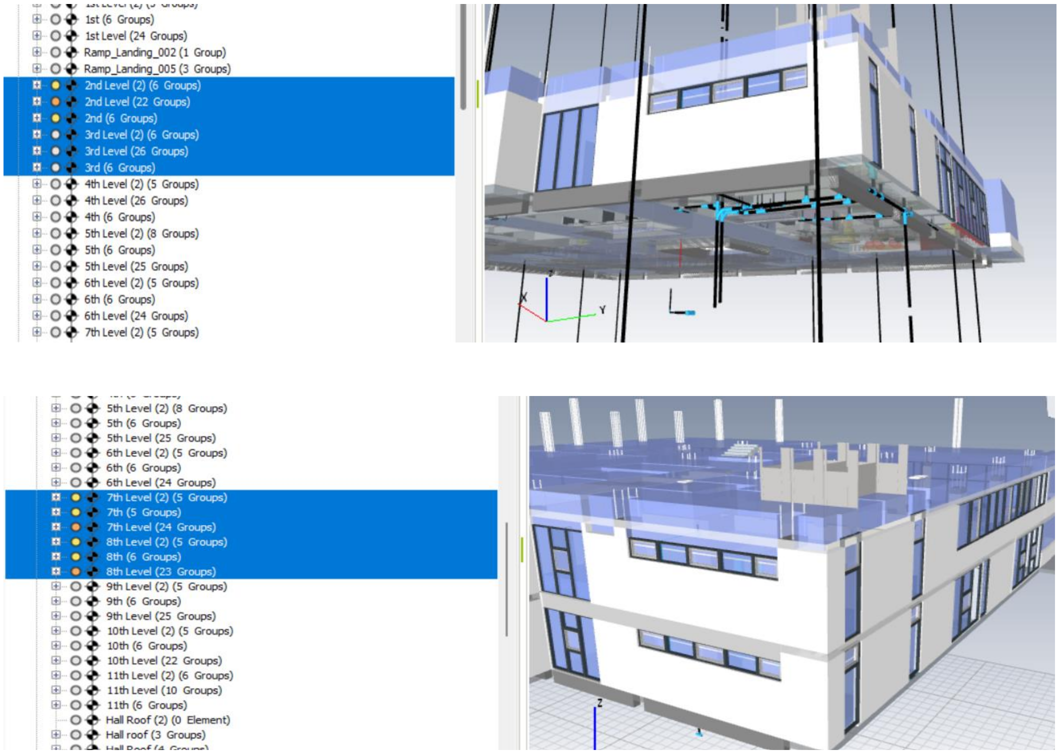


Figure 55 Visual Inspection of the Model

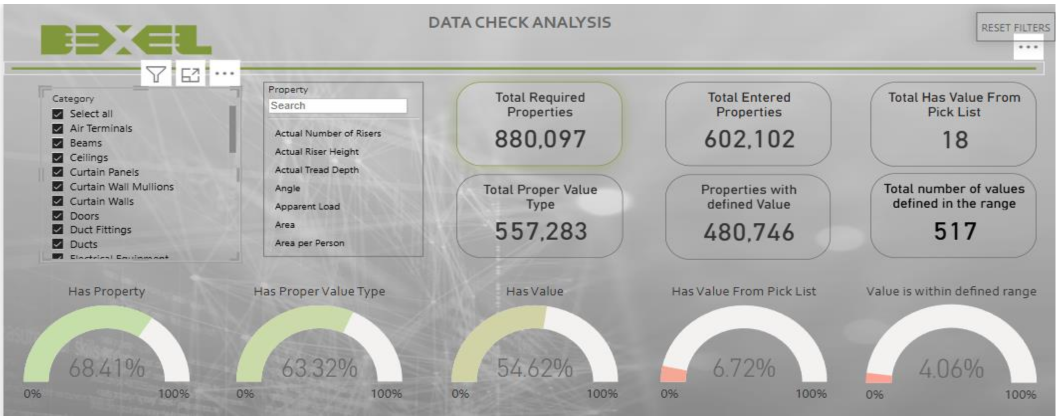
This issue arises because the models are generic, which does not comply with ISO 19650 standards for Level of Detail (LOD).

Results:

- **Low-Level Model Detail:** The lack of adherence to LOD standards affects the model's usability for 4D/5D BIM processes, as critical details required for scheduling and cost estimation are missing.
- **Element Misalignment:** The horizontal offsets make it difficult to accurately simulate construction sequences (4D BIM), as elements are not placed correctly in their spatial context.
- **Inaccurate Quantity Takeoffs:** Misaligned elements lead to incorrect material quantities, impacting cost estimation (5D BIM).

5.3.7.2 Automated Data Validation Process

Automated validation was conducted to identify data inconsistencies during the initial review phase, ensuring that models are compatible across tools and disciplines, thereby reducing coordination issues.



Data Check Analysis

Category / Property	Properties	Has Property	Has Property %	Has Value	Has Value %	Has Proper Value Type	Has Proper Value Type %	Has Value From Pick List	Has Value From Pick List %	Value is within defined range	Value is within defined range %
Air Terminals	**1,806**	**1,012**	**56.04**	**891**	**49.34**	**883**	**48.89**	**0**	**0.00**	**0**	**0.00**
Area	129	129	100.00	129	100.00	129	100.00	0	0.00	0	0.00
Description	129	129	100.00	109	84.50	129	100.00	0	0.00	0	0.00
Flow	129	129	100.00	129	100.00	0	0.00	0	0.00	0	0.00
Height	129	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Keynote	129	129	100.00	28	21.71	129	100.00	0	0.00	0	0.00
Phase Created	129	129	100.00	129	100.00	129	100.00	0	0.00	0	0.00
Size	129	129	100.00	129	100.00	129	100.00	0	0.00	0	0.00
Static Pressure Drop	129	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Static Pressure Loss	129	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
System Name	129	109	84.50	109	84.50	109	84.50	0	0.00	0	0.00
System Type	129	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total Pressure	129	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Volume	129	129	100.00	129	100.00	129	100.00	0	0.00	0	0.00
Width	129	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Beams	**31,434**	**19,344**	**61.54**	**16,926**	**53.85**	**19,344**	**61.54**	**0**	**0.00**	**0**	**0.00**
Area	2,418	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Construction Sequence	2,418	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Cut Length	2,418	2,418	100.00	2,418	100.00	2,418	100.00	0	0.00	0	0.00
Depth	2,418	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	**880,097**	**602,102**	**68.41**	**480,746**	**54.62**	**557,283**	**63.32**	**18**	**6.72**	**517**	**4.06**

Figure 56 Summarized Data Check Analysis for Project B

Results:

Error Reduction: Automated validation identified over 96% of data inconsistencies during the initial review phase.

5.3.7.3 Automated Model Data Enrichment

✓	UniClass Code	BEXEL Added
✓	UniClass Description	BEXEL Added
✓	Uniformat 2010 Description	BEXEL Added
✓	Uniformat 2010 Code	BEXEL Added
✓	Uniformat II Code	BEXEL Added
✓	Uniformat II Description	BEXEL Added

Figure 57 Automated Model Data Enrichment for Project B

Figure 58 displays the 15,000 undefined elements remaining after data enrichment. These elements are highlighted as problematic components that require additional definition and classification.

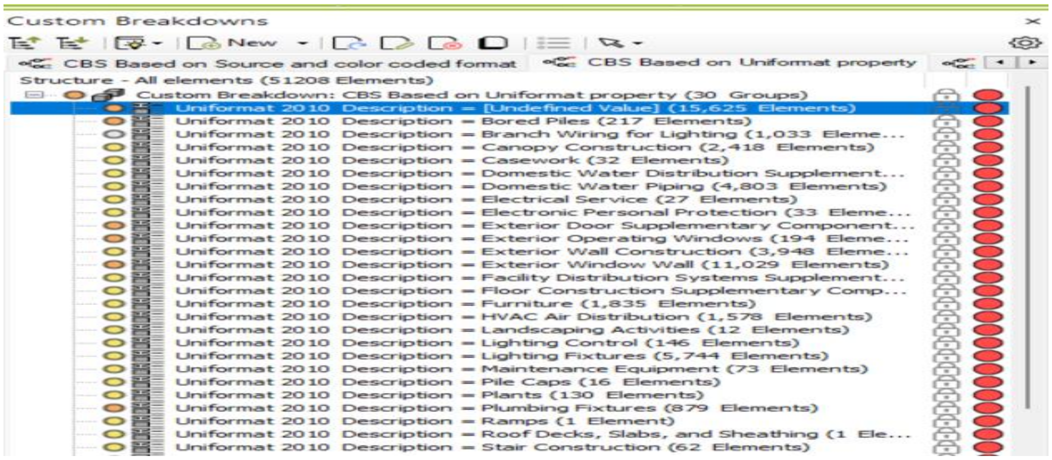


Figure 58 Automated Model Data Enrichment Result for Project B

Despite efforts to enrich data using Uniformat, Uniclass, and MasterFormat standards, approximately 15,000 elements remain undefined due to the generic nature of the model.

Impact on BIM Implementation:

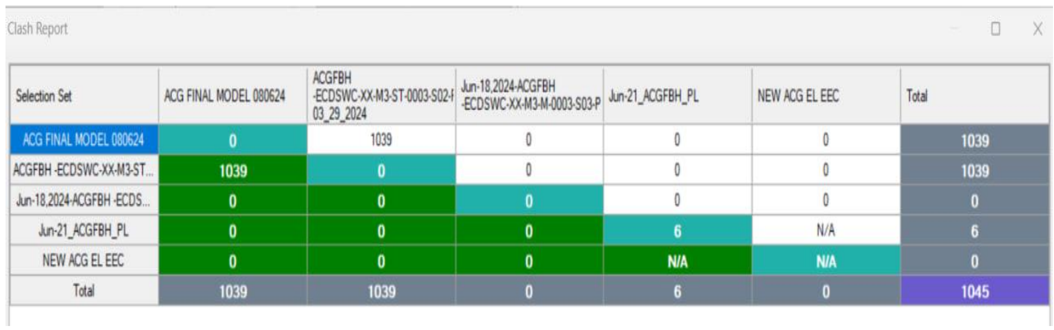
- **Incomplete Data for 4D/5D Processes:** Undefined elements lack critical information, such as material properties, quantities, and scheduling data, making them unusable in 4D (construction scheduling) or 5D (cost estimation) workflows.
- **Reduced Automation:** The presence of undefined elements requires manual intervention for data validation, reducing the efficiency of automated 4D/5D BIM processes.
- **Project Delays:** Undefined elements can cause delays as they need to be resolved before the model can be used for downstream applications.

5.3.7.4 Clash Detection

A duplicate bound clash exists between the AR and ST models because the AR model includes partial data from the ST model.

Key Findings:

Figure 59 illustrates the duplicate bound clash between elements in the AR and ST models, showing overlapping or redundant components flagged during clash detection.



Clash Report

Selection Set	ACG FINAL MODEL 080624	ACGFBH -ECDSWC-XX-M3-ST-0003-S02-f 03_29_2024	Jun-18,2024-ACGFBH -ECDSWC-XX-M3-M-0003-S03-P	Jun-21_ACGFBH_PL	NEW ACG EL EEC	Total
ACG FINAL MODEL 080624	0	1039	0	0	0	1039
ACGFBH -ECDSWC-XX-M3-ST...	1039	0	0	0	0	1039
Jun-18,2024-ACGFBH -ECDS...	0	0	0	0	0	0
Jun-21_ACGFBH_PL	0	0	0	6	N/A	6
NEW ACG EL EEC	0	0	0	N/A	N/A	0
Total	1039	1039	0	6	0	1045

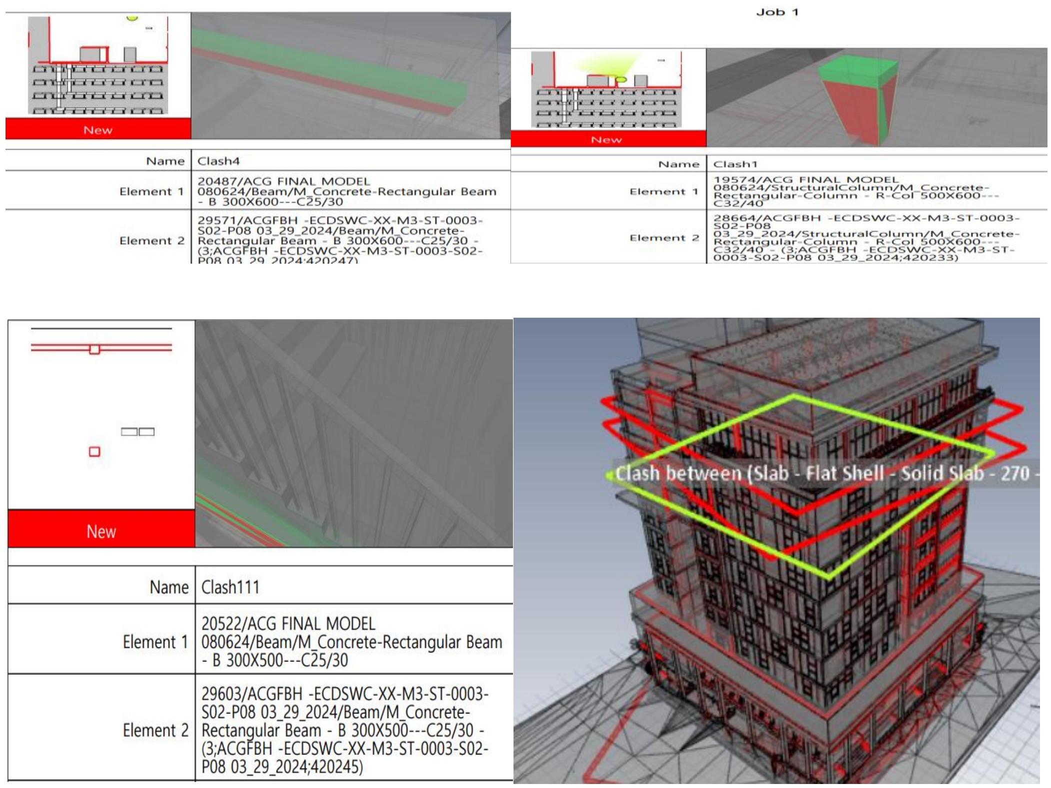


Figure 59 Clash Detection Report for Project B

Impact on BIM Implementation:

- **Clash Detection Inefficiencies:** Duplicate elements result in redundant clash detections, complicating the resolution process and increasing the time required for model validation.
- **Data Redundancy:** Partial duplication of structural data in the architectural model leads to inconsistencies in scheduling and cost estimation workflows.
- **Coordination Issues:** Duplicate clashes disrupt the coordination between disciplines, which is critical for 4D/5D BIM implementation.

5.4 4D/5D BIM Implementation on Project C: Ethiopian Petroleum Station Mixed-Use Building

Project Overview: A 2B+G+14 mixed-use building with a contract amount of 1.5 billion birr.

Project Timeline

- **Start Date**: April 2024
- **Expected Completion**: April 2026

Location: Akaki, Addis Ababa

Since Project B and Project C is managed by the same company, both projects share the same BIM objectives, use cases, BIM management team structure, BIM maturity level, BIM software and tools, as well as the Common Data Environment (CDE).

5.4.1 4D/5D BIM Process: The Implementation

Federated BIM models are exported to BX3 format using the Revit Publisher.

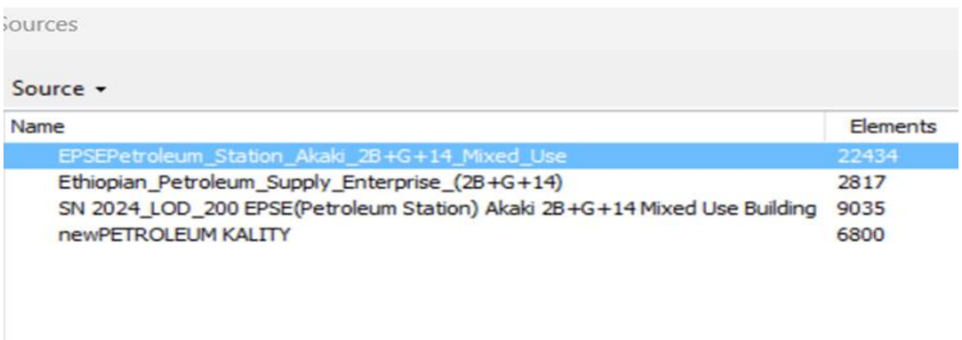


Figure 60 Federated BIM Revit Models for Project C

General Project Information

The Project

Figure 61 represent the model from multiple perspectives (front, back, left, right, and top views), showcasing how the misalignment affects the overall spatial relationships within the project. The lack of a unified work plane leads to discrepancies in model integration, which can result in clashes, inefficiencies, and potential delays during the construction phase.

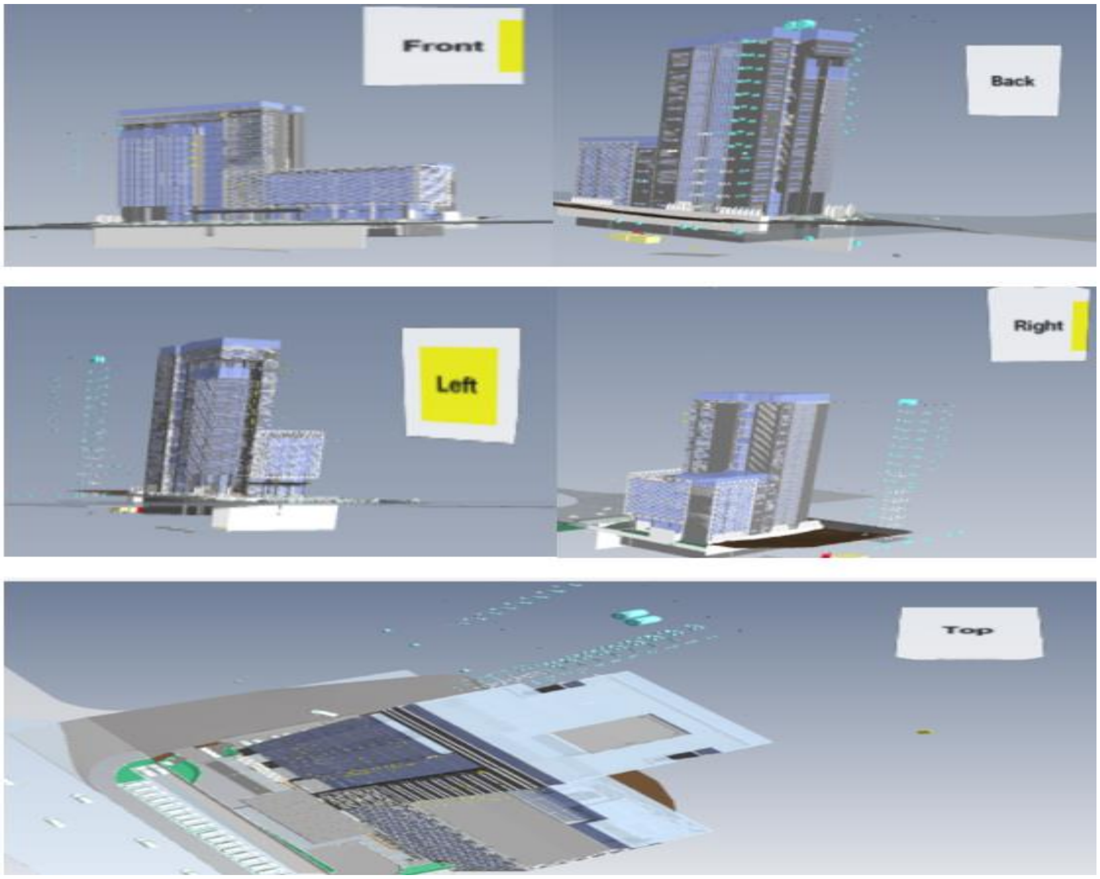


Figure 61 3D Model View of Project C

Result:

As shown in the 3D model, **Figure 61** noticeable offsets in the sanitary drawings can be observed. These offsets are a result of using inconsistent work planes during the modeling process. One of the fundamental principles in Building Information Modeling (BIM) is the adoption of an agreed-upon work plane and coordinate system by all stakeholders. This ensures proper alignment and coordination between various disciplines, such as architectural, structural, and MEP systems.

It is critical to establish and enforce a standardized coordinate system and work plane across all disciplines at the outset of the project. This practice not only enhances the accuracy of the model but also ensures seamless coordination, improving the reliability and efficiency of the BIM workflows.

5.4.1.1 Model Data Management

Initial Model Review

The Initial Model Review conducted in BEXEL Manager provided insights into model sources, organization, accuracy, and level of detail (LOD).

Key Findings:

Model Sources: Federated models were successfully imported from Revit, with all geometry and metadata intact.

Model Organization: The source models (AR, ST, and MEP) have different work planes, resulting in duplicated stories when linked in Revit and exported as IFC files for subsequent use in BEXEL Manager. As illustrated in the figure, this discrepancy leads to an excess of the intended 17 floors, with over 61 stories present.

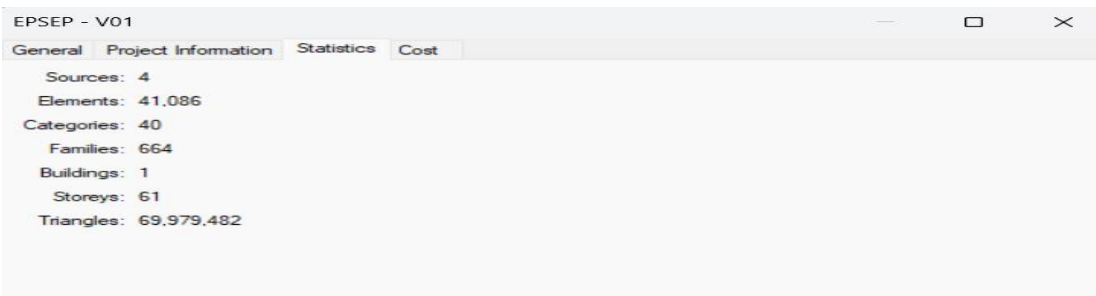


Figure 62 Model Source and Organization of Project C

Visual Inspection: **Figure 63** demonstrate the offset elements showing components displaced above, below their intended floors and displaced from the building coordinate.

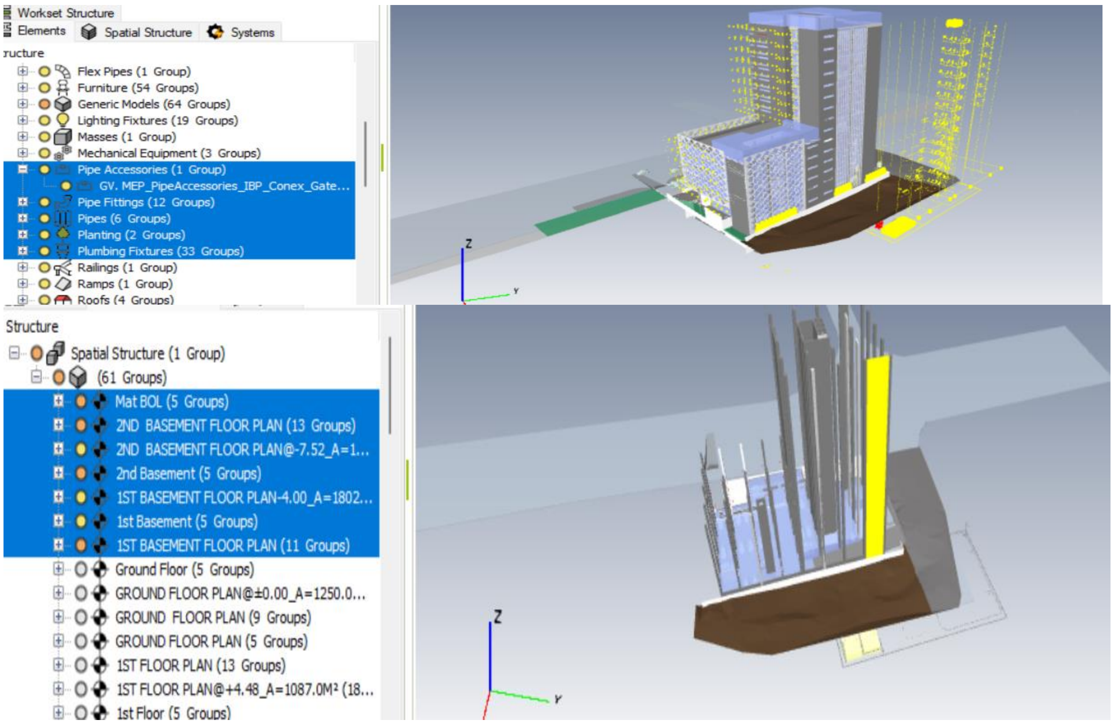


Figure 63 Visual Inspection of the Model C

This issue arises because the models are generic, which does not comply with ISO 19650 standards for Level of Detail (LOD).

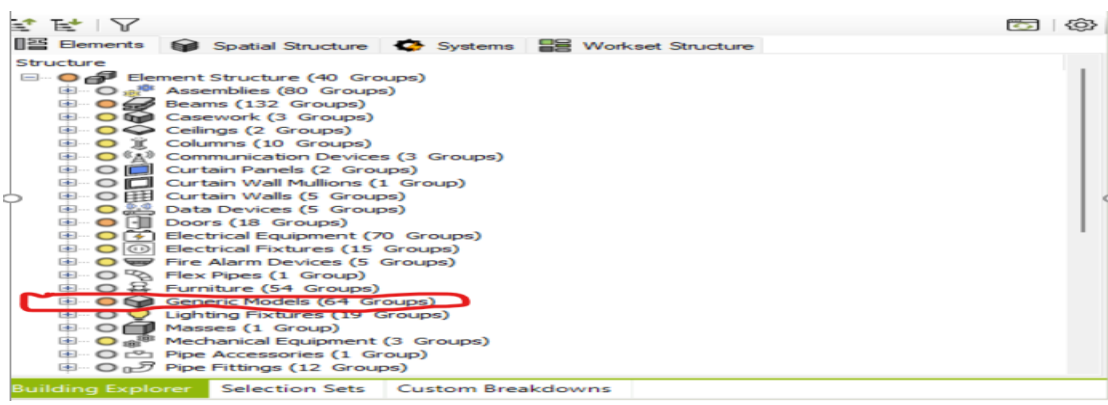
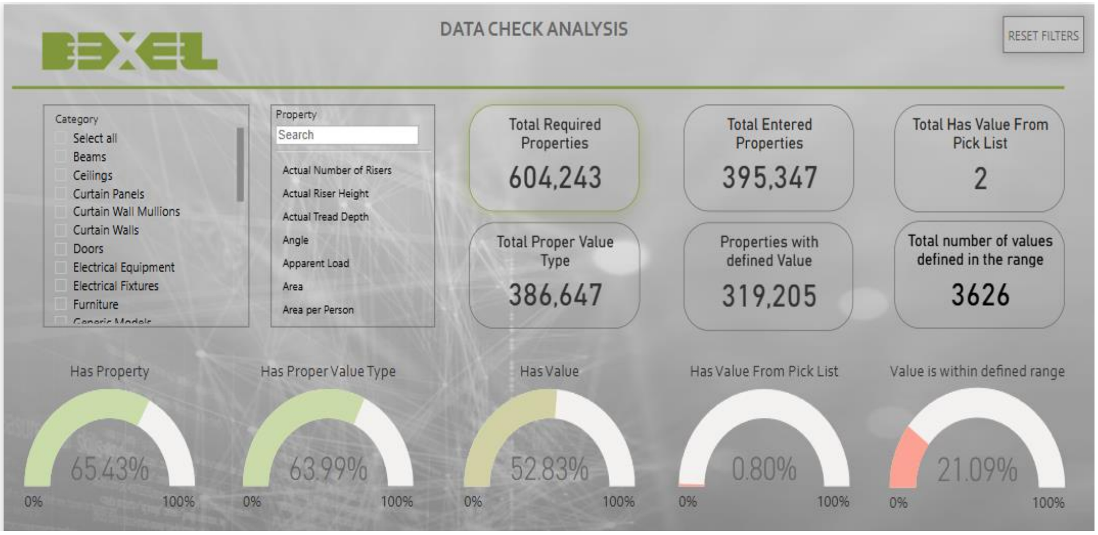


Figure 64 Generic Model Groups of Project C

5.4.1.2 Automated Data Validation Process

Automated validation was conducted to identify data inconsistencies during the initial review phase, ensuring that models are compatible across tools and disciplines, thereby reducing coordination issues.



Data Check Analysis											
Category / Property	**Properties**	**Has Property**	**Has Property %**	**Has Value**	**Has Value %**	**Has Proper Value Type**	**Has Proper Value Type %**	**Has Value From Pick List**	**Has Value From Pick List %**	**Value is within defined range**	**Value is within defined range %**
Reference Level Elevation											
UniFormat	2,322	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Volume	2,322	2,322	100.00	2,322	100.00	2,322	100.00	0	0.00	0	0.00
Curtain Wall Mullions	**133,752**	**100,314**	**75.00**	**89,168**	**66.67**	**100,314**	**75.00**	**0**	**0.00**	**0**	**0.00**
Angle	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
Area	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
Computation Height	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
Construction Sequence	11,146	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Keynote	11,146	11,146	100.00	0	0.00	11,146	100.00	0	0.00	0	0.00
Length	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
MasterFormat	11,146	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Offset	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
Phase Created	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
Thickness	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
UniFormat	11,146	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Volume	11,146	11,146	100.00	11,146	100.00	11,146	100.00	0	0.00	0	0.00
Curtain Walls	**2,970**	**2,177**	**73.30**	**1,979**	**66.63**	**1,781**	**59.97**	**0**	**0.00**	**0**	**0.00**
Angle	198	198	100.00	198	100.00	198	100.00	0	0.00	0	0.00
Total	**604,243**	**395,347**	**65.43**	**319,205**	**52.83**	**386,647**	**63.99**	**2**	**0.80**	**3626**	**21.09**

Figure 65 Summarized Data Check Analysis Results of Project C

Results:

Error Reduction: Automated validation identified over 79% of data inconsistencies during the initial review phase.

5.4.1.3 Automated Model Data Enrichment

✓	UniClass Code	BEXEL Added
✓	UniClass Description	BEXEL Added
✓	Uniformat 2010 Description	BEXEL Added
✓	Uniformat 2010 Code	BEXEL Added
✓	Uniformat II Code	BEXEL Added
✓	Uniformat II Description	BEXEL Added

Import | Import Ids | Phase: Issue for Construction | Evaluate | Generate Statistics (CBS) | Selection | Create Selectio

Drag a column here to group by this column.

Name	Status	No. Checked Elements	No. Passed Elements	Success %	Result
Masses	Done	1	0	0.00%	
Windows	Done	107	0	0.00%	
Curtain Wall Mullions	Done	11146	0	0.00%	
Structural Columns	Done	114	0	0.00%	
Sites	Done	118	0	0.00%	
Roofs	Done	13	0	0.00%	
Plumbing Fixtures	Done	1375	0	0.00%	
Furniture	Done	1498	0	0.00%	
Ceilings	Done	17	0	0.00%	
Curtain Walls	Done	198	0	0.00%	
Lighting Fixtures	Done	2241	0	0.00%	
Beams	Done	2322	0	0.00%	
Spaces	Done	249	0	0.00%	
Generic Models	Done	2743	0	0.00%	
Planting	Done	281	0	0.00%	
Structural Foundations	Done	29	0	0.00%	
Slabs	Done	329	0	0.00%	
Electrical Equipment	Done	342	0	0.00%	
Pipes	Done	3718	0	0.00%	
Pipe Fittings	Done	3987	0	0.00%	
Railings	Done	49	0	0.00%	
Mechanical Equipment	Done	5	0	0.00%	
Curtain Panels	Done	5058	0	0.00%	
Stairs	Done	52	0	0.00%	
Electrical Fixtures	Done	653	0	0.00%	
Property Naming Conventions	Done	659	177	26.86%	

Figure 66 Automated Model Data Enrichment Result of Project C

The evaluation results reveal significant validation issues across most categories, with a 0% success rate indicating that the elements failed to meet the validation criteria, which may point to problems such as missing data or incorrect metadata. Notably, while the Property Naming Conventions category shows a partial success rate of 26.86%, the majority still requires corrections. Critical categories like Plumbing Fixtures, Pipe Fittings, and Electrical Equipment demonstrate a high number of checked elements but lack compliance, suggesting these issues could severely impact project coordination and accuracy. Overall, the findings highlight the need for immediate attention to ensure the BIM model's integrity and adherence to standards.

5.4.1.4 Clash Detection

A Hard and clearance clash exists between the AR and MEP models.

Key Findings:

- This image shows a clearance clash, where elements (highlighted in red) do not meet the required spatial tolerances or clearances. Such clashes often occur between structural or architectural elements and MEP systems, causing coordination inefficiencies. This type of clash can lead to operational or maintenance difficulties if not resolved during the design phase.

- A hard clash have been identified, the red-highlighted elements indicate the clashing components and the ceiling above and other surrounding building systems are shown in gray, indicating the spatial context of the clash.

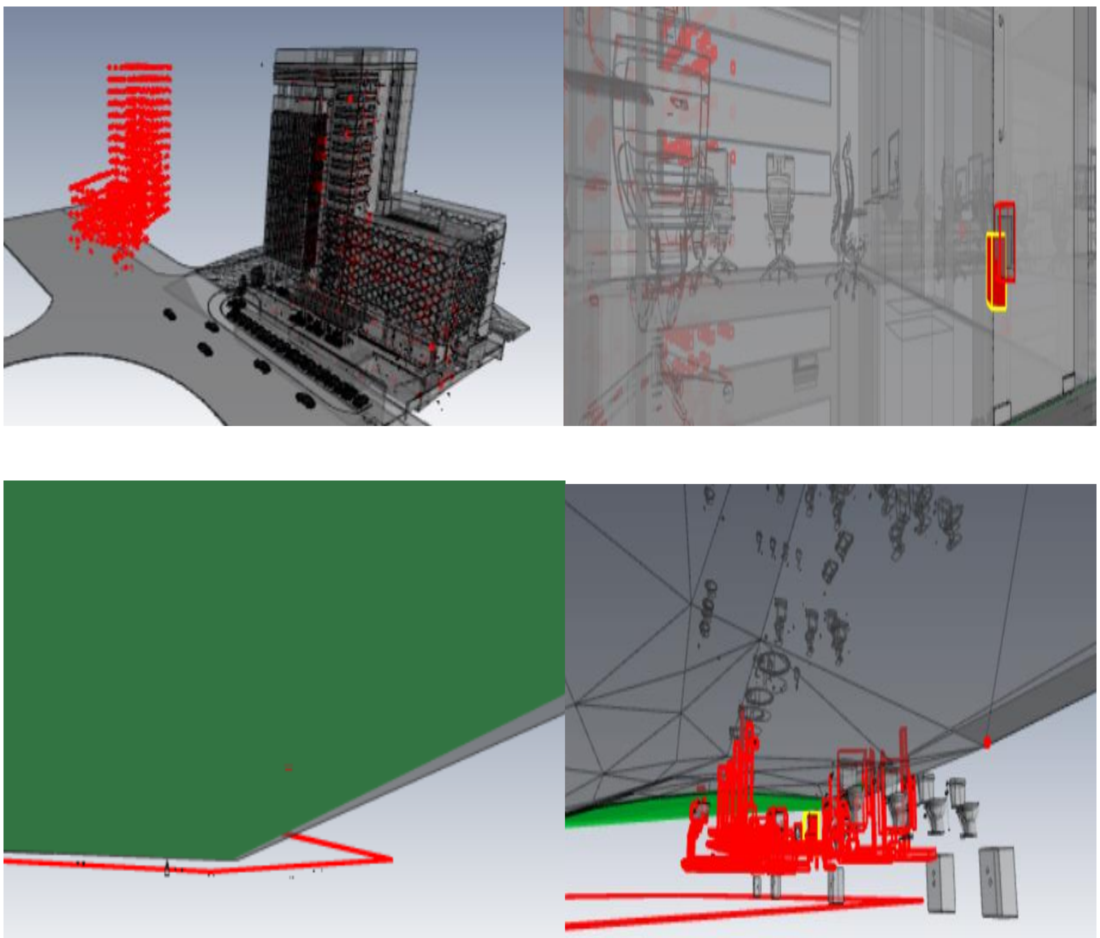


Figure 67 Clash Report of Project C

Impact on BIM Implementation:

Unresolved clashes can significantly hinder the 4D/5D BIM application process on projects.

- **Workflow Disruption**: Clashes create complications in the workflow, making it difficult for teams to coordinate and collaborate effectively. This can lead to inefficient use of time and resources during the planning and execution phases.
- **Data Integrity Issues**: Inconsistent data due to clashes can compromise the accuracy of the 4D/5D models. This undermines the reliability of simulations and analyses, making it challenging to create effective schedules and budgets.
- **Rework and Iteration**: The need to repeatedly address clashes can lead to excessive iterations in the model. This not only slows down progress but can also frustrate team members and stakeholders.
- **Compromised Decision-Making**: Inaccurate models hinder decision-making processes, as stakeholders may not have the full picture of project implications. This can lead to poor planning and execution choices.
- **Reduced Visualization Effectiveness**: The ability to visualize project timelines and costs accurately is diminished when clashes exist, impacting the overall utility of 4D and 5D BIM tools.

Discussions on Project B and C

The challenges outlined in Project B and C stem from failure to adhere to ISO 19650 standards, resulting in major inefficiencies and inconsistencies in the BIM process. The lack of critical documents, such as the BEP and the EIR, has further compounded these issues. Currently, the company operates at the 3D BIM level, focusing only on geometric modeling without full parametric modeling, which has limited the ability to fully leverage the benefits of BIM. Below is an elaboration on how these factors are interconnected and how adherence to ISO 19650 standards, including BEP and EIR development, could address the challenges.

1. Lack of Compliance with ISO 19650 Standards

ISO 19650 standards provide a structured framework for managing information throughout the lifecycle of a built asset using BIM. Project B and Ci failure to align with these standards has resulted in:

- **Unstructured Information Management:** The absence of standardized processes for model creation, sharing, and coordination has led to inconsistencies such as work plane discrepancies, undefined elements, and misaligned models.
- **Poor Collaboration:** Without a defined framework, including shared responsibilities and data standards, there is no efficient method for integrating architectural,

structural, and MEP models. This has caused issues like duplicate bound clashes, story misalignments, and unintended elements.

2. Absence of BEP and EIR

The lack of BEP and EIR has directly contributed to the problems identified. These documents are essential for ensuring clarity and consistency in BIM workflows.

BIM Execution Plan (BEP):

The BEP is a critical document that outlines the processes, standards, and protocols to be followed in a BIM project. The absence of a BEP has led to the following issues:

- **File Naming Convention Issues:** Without a standard naming convention, model files from different disciplines are mismanaged, resulting in coordination challenges. For example, inconsistent file names make it difficult to identify and link AR, ST, and MEP models accurately.
- **Coordinate System Misalignment:** A BEP would define a unified coordinate system for all disciplines, preventing the work plane discrepancies and horizontal offsets seen in the current models.
- **No Defined Model LOD Requirements:** The lack of a BEP has resulted in models that do not meet the required Level of Detail (LOD) for 4D/5D workflows, making it impossible to use the models effectively for construction sequencing and cost estimation.

Employer's Information Requirements (EIR):

The EIR outlines the client's information needs and sets clear expectations for BIM deliverables. The absence of an EIR has caused:

- **Undefined Data Requirements:** This has led to approximately 15,000 undefined elements in the model, as there were no clear guidelines for data enrichment using standards like Uniformat, Uniclass, and MasterFormat.
- **Inconsistencies in Deliverables:** Without an EIR, the project team does not have a clear understanding of what information is required for 4D and 5D BIM, resulting in incomplete or redundant data.

3. Current Implementation Limited to 3D BIM

The company's current focus on 3D BIM (geometric modeling) has restricted their ability to transition to BIM dimensions like 4D and 5D. This limitation has exacerbated the challenges:

- **Inability to Use Models for Construction Sequencing (4D BIM):** Misaligned work planes, extra stories, and undefined elements make it impossible to simulate construction schedules accurately.
- **Cost Estimation Errors (5D BIM):** Duplicated elements and unresolved clashes inflate material quantities, leading to unreliable cost estimates.

4. Generic Models

Using generic models in BIM implementation comes with several disadvantages, particularly when aiming to achieve BIM dimensions such as 4D and 5D. The key disadvantages of relying on generic models:

Lack of Specificity and Accuracy

- **No Defined Properties:** Generic models lack detailed information about materials, structural properties, or element classifications, making them unsuitable for precise simulations and analyses.
- **Inconsistent Data:** Since generic models are not tailored to specific BIM standards like Uniformat, Uniclass, or MasterFormat, they often fail to provide the required level of accuracy for construction planning or facility management.
- **Reduced LOD/LOI:** Generic models typically do not meet the necessary LOD or LOI, which are critical for tasks like scheduling and cost estimation.

Difficulty in 4D/5D BIM Implementation

- **Scheduling Challenges (4D BIM):** Without defined parameters such as element types, materials, or relationships, generic models cannot be accurately linked to project schedules. This leads to incomplete or inaccurate construction sequence simulations.
- **Cost Estimation Issues (5D BIM):** Since generic models lack detailed quantities and classifications, they cannot provide reliable data for quantity takeoffs or cost estimation, resulting in errors and inefficiencies.

Non-Compliance with BIM Standards

- **ISO 19650 Misalignment:** Generic models do not adhere to the structured workflows and data management principles outlined in standards like ISO 19650. This non-compliance makes it challenging to integrate them with other discipline specific models.
- **Clash Detection Problems:** Without detailed specifications and classifications, generic models can cause false positives or overlooked clashes during coordination and clash detection processes.

Limited Automation and Interoperability

- **Data Enrichment Required:** Generic models often require significant manual data enrichment to meet project requirements. This adds time and cost to the BIM process.
- **Interoperability Challenges:** Generic models are less compatible with BIM software and workflows, especially when exporting to formats like IFC, making it difficult to integrate them into a collaborative environment.

Increased Risk of Errors

- **Inaccurate Representation:** Generic models may not reflect the actual design or construction intent, leading to discrepancies between the virtual model and the physical asset.
- **Coordination Issues:** The lack of detailed data in generic models increases the likelihood of misalignments and errors during model coordination.

By developing a robust BEP with standardized file naming conventions, a unified coordinate system, and clearly defined LOD/LOI requirements, the company can resolve these issues and enable successful 4D/5D BIM implementation. Following ISO19650 standards will also improve collaboration, reduce errors, and enhance the overall efficiency of BIM workflows.

5.5 BIM Maturity Assessment: Interview Insights with the BIM Manager of Project B and C

The BIM Maturity Spider Radar Assessment provides a comprehensive evaluation of the current state of BIM implementation within the organization. This assessment identifies critical gaps in compliance, process standardization, and 4D/5D BIM dimensions. Using the

ISO 19650 framework as a benchmarking tool, this section outlines the current challenges, maturity levels, and a roadmap for improvement. The findings are presented through a detailed radar matrix, visual representation, and actionable recommendations to achieve higher BIM maturity levels.

1. Current vs Target BIM Maturity Radar

The maturity of BIM implementation was analyzed across eight critical dimensions, each evaluated on a scale of 0 to 5. The current scores were compared with the target scores to identify gaps and prioritize improvements.

Table 5-7 BIM Maturity Performance Score for Project B and C

Category	Current Score	Target Score	Gap
ISO 19650 Compliance	1.5	4.5	3
BEP Implementation	1	4.5	3.5
EIR Development	1	4.5	3.5
Model Development	2	4.5	2.5
Data Management	1.5	4	2.5
Standards Adoption	1.5	4.5	3
4D/5D Implementation	1	4	3
Collaboration Framework	1.5	4.5	3

This matrix highlights critical gaps in BEP and EIR implementation, standards adoption, and advanced BIM functionalities, emphasizing the urgency for structured improvements.

2. Strengths and Achievements

❖ **Current State Assessment**

The organization currently operates at Level 1-2 (Initial/Managed) in the BIM maturity scale. Fragmented workflows, limited documentation, and basic 3D modeling characterize this level.

❖ **Maturity Level Distribution**

The current maturity is limited to basic 3D modeling and minimal standards adoption, while the target is to achieve Level 4 (Integrated) or Level 5 (Optimized).

Table 5-8 Maturity Level Distribution

Level	Description	Current Areas	Target Areas
Level 1 • 4D/5D Implementation	Initial None	BEP/EIR	
Level 2 • Basic Standards	Managed None	Model Development	
Level 3 • Standard Processes	Defined	None	Basic Workflows
Level 4	Integrated	None	Most Areas
Level 5	Optimized	None	Key Processes

3. **Visual Spider Radar Representation**

The spider radar chart visually represents the current and target maturity scores across the eight dimensions.

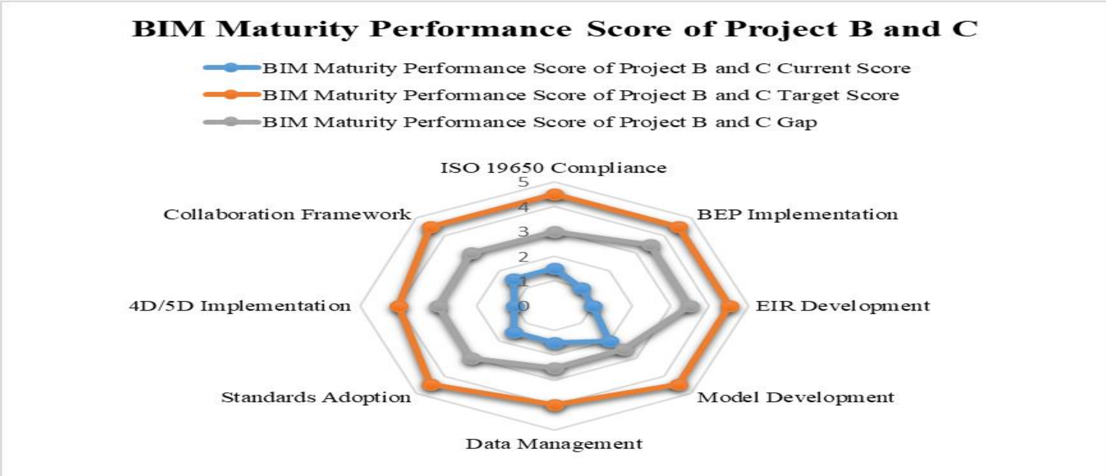


Figure 68 BIM Maturity Assessment for Project B and C

4. **Priority Improvement Areas and Road maps**

Table 5-9 Improvement Areas and Road maps for Project B and C

Priority	Area	Current Issues	Recommended Actions
High • No standards • Poor coordination • Create detailed EIR • Implement standards	BEP/EIR	• Missing documentation	Develop BEP and EIR, establish basic standards, and align workflows with ISO 19650 principles.
Medium • Poor data structure • Limited functionality • Implement classifications • Improve data structure	Model Development	• Generic models	Adopt ISO 19650 across all workflows, enhance model detail (LOD/LOI), and improve data management structures.
Ongoing • Inconsistent processes • Limited integration • Standardize processes • Enhance integration	Standards & Compliance	• Non-compliance	Adopt ISO 19650 Implement 4D BIM (time scheduling) and 5D BIM (cost estimation), optimize workflows, and achieve full integration of BIM

The BIM Maturity Spider Radar Assessment highlights significant gaps in the organization's current BIM practices, particularly in BEP/EIR development, ISO 19650 compliance, and 4D/5D implementation. By following the proposed roadmap, the organization can transition from its current state of basic 3D modeling to a fully integrated and optimized BIM environment. Implementing these changes will not only address the identified issues but also enhance collaboration, efficiency, and project outcomes.

6 Conclusion and Recommendation

6.1 Conclusion

The study focused on the implementation of 4D/5D BIM in the Ethiopian construction industry by analyzing three case studies: Project A (The New Ethiopian National Theater), Project B (Addis Capital Goods 2B+G+11 Mixed-Use Building), and Project C (Ethiopian Petroleum Station Mixed-Use Building). The findings of this research, derived from the case studies align closely with established literature and international standards, reinforcing the benefits, challenges, and lessons learned associated with 4D and 5D BIM implementation. Based on the findings and analysis of the implemented framework, the following conclusions are drawn:

6.1.1 Objective 1: Identified Benefits of 4D/5D BIM Implementation

Enhanced collaboration, **improved planning**, **accurate cost estimation**, **data-driven decision-making**, and **minimized construction errors** were observed to play a significant role in advancing project outcomes. These benefits are well documented across BIM literature. For instance, Eastman et al. (2011) and Azhar (2011) emphasize that integrating 4D and 5D BIM allows stakeholders to link 3D model elements with schedules and cost data, resulting in more accurate planning, sequencing, and resource allocation. Similar benefits have been identified by Kymmell (2008) and McPartland and Kouider (2017), who highlight that visual simulations and automated quantity takeoff tools reduce errors, mitigate delays, and enable more precise cost forecasting and budget control. Moreover, the role of BIM in facilitating data-driven decision-making through automated analytics has been confirmed by Succar (2009), aligning with this study's findings about its contribution to transparency and accountability.

6.1.2 Objective 2: Assessed Challenges in 4D/5D BIM Implementation

Objective two of this study assessed the key challenges encountered in implementing 4D/5D BIM. The results revealed issues related to the **lack of standardized processes, limited expertise**, **high initial investment, resistance to digital methods**, and **insufficient collaboration platforms**. These findings are well corroborated in literature. The significance of early adoption of standardized approaches such as ISO 19650 is emphasized by Borrmann et al. (2018) and ISO 19650-1 (2018), which advocate for robust information management and structured delivery protocols. Belay et al. (2021) and Azhar (2011) as a critical barrier, highlighting the need for sustained investment in capacity-building and training, have identified the shortage of trained BIM professionals. Similarly, Barlish and Sullivan (2012) point to the high upfront costs of BIM implementation as an obstacle that can limit its effective deployment, aligning with the case findings. The resistance to digital methods observed in the case studies further mirrors the observations by Succar (2009) and Alaloul et al. (2020), which highlight the cultural and organizational changes required to support digitalization. Moreover, the critical role of cloud-based Common Data Environments (CDE) for facilitating seamless collaboration and version control is extensively emphasized in the literature (Eastman et al., 2011; McPartland & Kouider, 2017).

6.1.3 Objective 3: Lessons Learned and Framework Development

Objective three focused on extracting lessons learned from the case studies and aligning these with best practices in BIM literature. The results underscore the critical role of **early adoption of ISO 19650 standards** in promoting consistency, collaboration, and interoperability across disciplines (Borrmann et al., 2018). The necessity of clearly defined **BIM Execution Plans (BEP)** and **Employer's Information Requirements (EIR)** is supported by international standards and literature as pivotal in eliminating ambiguity and aligning stakeholders throughout the project lifecycle (Eastman et al., 2011). The findings also emphasize the importance of **investing in staff training** and **skill development**, aligning with observations by Belay et al. (2021) and Azhar (2011). McPartland and Kouider (2017) and Eastman et al. (2011) corroborate the benefits of leveraging **cloud-based CDE platforms** for improved data sharing, version control, and issue tracking. Similarly, Monteiro and Martins (2013) and Azhar (2011) extensively discuss the role of **automated clash detection, data validation, and quantity takeoff tools** in reducing manual errors and boosting project efficiency.

- **Framework Development:**

A framework for 4D/5D BIM implementation was developed in alignment with ISO 19650 standards and Ethiopian Standard ES ISO/IEC and applied to the selected building projects as a case study for validation. This framework emphasizes the significance of stakeholder training, the phased adoption of BIM technologies, and the integration of BIM processes into existing project management workflows. Additionally, it underscores the necessity of government and industry support to overcome financial and technical challenges.

In summary, the case studies conducted in this research closely mirror the observations and conclusions in the wider body of literature. The benefits, challenges, and lessons learned underscore the critical role of structured BIM implementation grounded in international and local standards complemented by a focus on training, collaboration, and technological investment in achieving improved project outcomes and advancing the construction industry in Ethiopia.

6.2 Recommendations

6.2.1 For Project A: The New Ethiopian National Theater

- **Improve CDE Usage:** Transition from the current platform to a cloud-based CDE for real-time collaboration and enhanced issue tracking.
- **Capacity Building:** Conduct targeted training for the project team on advanced BIM tools like BEXEL Manager for 4D/5D workflows.
- **Strengthen Stakeholder Communication:** Use BIM visualizations for stakeholder engagement, ensuring alignment on project goals and progress.

6.2.2 For Project B: Addis Capital Goods Mixed-Use Building and Project C: Ethiopian Petroleum Station Mixed-Use Building

- **Address Work Plane Misalignments:** Standardize coordinate systems across all disciplines to eliminate duplicated stories and misaligned elements.
- **Resolve Generic Model Issues:** Upgrade models to comply with ISO 19650 standards, Ethiopian Standard ES ISO/IEC and incorporate metadata for better integration into 4D/5D workflows.
- **Implement Monthly BIM Reviews:** Conduct regular reviews to identify and resolve issues early, ensuring continuous model improvement.
- **Enhance Clash Detection Processes:** Use structured clash detection workflows and assign resolutions through BCF formats to improve coordination.
- **Adopt Cloud-Based Collaboration:** Move from a local server to a centralized CDE for improved collaboration and document traceability.
- **Increase BIM Skills:** Provide training for project teams on advanced BIM functionalities, including 4D scheduling and 5D cost management.

6.3 Future Research and Development:

- This research does not include the full integration of mechanical systems for project A, as the initial design was developed using conventional methods and underwent subsequent design changes. The study was conducted based on the data available at the time. Further research is recommended to achieve comprehensive integration of construction simulation and progress monitoring.
- Conduct further research to explore the long-term impacts of 4D/5D BIM on project outcomes, including sustainability and lifecycle cost analysis.
- Investigate the potential for integrating emerging technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), with BIM to enhance its capabilities.

By addressing the identified challenges and leveraging the lessons learned, the Ethiopian construction industry can unlock the full potential of 4D/5D BIM. The successful implementation of the proposed framework in Projects A, B, and C serves as a benchmark for future projects, paving the way for a more efficient, collaborative, and technologically advanced construction sector in Ethiopia.

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Appendix A: Data Check Analysis (Model Data Validation) for Project A

Category / Property	Property	Element Count	Has Property	Has Property Percentage	Has Value	Has Value Percentage	Has Proper Value Type	Has Proper Value Type Percentage
Air Terminals	Area	3	3	100	3	100	3	100
Air Terminals	Description	3	3	100	0	0	3	100
Air Terminals	Flow	3	3	100	3	100	0	0
Air Terminals	Height	3	0	0	0	0	0	0
Air Terminals	Keynote	3	3	100	0	0	3	100
Air Terminals	Phase Created	3	3	100	3	100	3	100
Air Terminals	Size	3	3	100	0	0	3	100
Air Terminals	Static Pressure Drop	3	0	0	0	0	0	0
Air Terminals	Static Pressure Loss	3	0	0	0	0	0	0
Air Terminals	System Name	3	0	0	0	0	0	0
Air Terminals	System Type	3	0	0	0	0	0	0
Air Terminals	Total Pressure	3	0	0	0	0	0	0
Air Terminals	Volume	3	3	100	3	100	3	100
Air Terminals	Width	3	0	0	0	0	0	0
Beams	Area	3261	0	0	0	0	0	0
Beams	Construction Sequence	3261	0	0	0	0	0	0
Beams	Cut Length	3261	3261	100	3261	100	3261	100
Beams	Depth	3261	0	0	0	0	0	0
Beams	Elevation at Bottom	3261	3261	100	3261	100	3261	100
Beams	Elevation at Top	3261	3261	100	3261	100	3261	100
Beams	Keynote	3261	3261	100	0	0	3261	100
Beams	Length	3261	3261	100	3261	100	3261	100
Beams	MasterFormat	3261	0	0	0	0	0	0
Beams	Phase Created	3261	3261	100	3261	100	3261	100
Beams	Reference Level Elevati	3261	3261	100	3261	100	3261	100
Beams	UniFormat	3261	0	0	0	0	0	0
Beams	Volume	3261	3261	100	3261	100	3261	100
Cable Tray Fittings	Area	6	6	100	6	100	6	100
Cable Tray Fittings	Bend Radius	6	5	83.33333	5	83.33333	5	83.33333333
Cable Tray Fittings	Construction Sequence	6	0	0	0	0	0	0
Cable Tray Fittings	Keynote	6	6	100	0	0	6	100
Cable Tray Fittings	MasterFormat	6	0	0	0	0	0	0
Cable Tray Fittings	Offset	6	0	0	0	0	0	0
Cable Tray Fittings	Phase Created	6	6	100	6	100	6	100
Cable Tray Fittings	Radius	6	1	16.66667	1	16.66667	1	16.66666667
Cable Tray Fittings	Size	6	6	100	6	100	6	100
Cable Tray Fittings	Thickness	6	6	100	6	100	6	100
Cable Tray Fittings	Tray Height	6	6	100	6	100	6	100
Cable Tray Fittings	Tray Length	6	6	100	6	100	6	100
Cable Tray Fittings	Tray Width	6	5	83.33333	5	83.33333	5	83.33333333
Cable Tray Fittings	UniFormat	6	0	0	0	0	0	0
Cable Tray Fittings	Volume	6	6	100	6	100	6	100
Cable Trays	Bottom Elevation	11	0	0	0	0	0	0
Cable Trays	Construction Sequence	11	0	0	0	0	0	0
Cable Trays	Height	11	11	100	11	100	11	100
Cable Trays	Keynote	11	11	100	0	0	11	100
Cable Trays	MasterFormat	11	0	0	0	0	0	0
Cable Trays	Phase Created	11	11	100	11	100	11	100
Cable Trays	Size	11	11	100	11	100	11	100
Cable Trays	Top Elevation	11	0	0	0	0	0	0
Cable Trays	UniFormat	11	0	0	0	0	0	0
Cable Trays	Width	11	11	100	11	100	11	100
Ceilings	Area	1458	1458	100	1458	100	1458	100
Ceilings	Construction Sequence	1458	0	0	0	0	0	0
Ceilings	Keynote	1458	1458	100	16	1.097394	1458	100
Ceilings	MasterFormat	1458	0	0	0	0	0	0
Ceilings	Phase Created	1458	1458	100	1458	100	1458	100

Category / Property	Property	Element Count	Has Property	Has Property Percentage	Has Value	Has Value Percentage	Has Proper Value Type	Has Proper Value Type Percentage
Ceilings	Room Bounding	1458	1458	100	1458	100	1458	100
Ceilings	Slope	1458	1458	100	1458	100	1458	100
Ceilings	Thickness	1458	1458	100	1458	100	1458	100
Ceilings	UniFormat	1458	0	0	0	0	0	0
Ceilings	Volume	1458	1458	100	1458	100	1458	100
Conduits	Bottom Elevation	2	0	0	0	0	0	0
Conduits	Construction Sequence	2	0	0	0	0	0	0
Conduits	Inside Diameter	2	2	100	2	100	2	100
Conduits	Keynote	2	2	100	0	0	2	100
Conduits	Length	2	2	100	2	100	2	100
Conduits	MasterFormat	2	0	0	0	0	0	0
Conduits	Outside Diameter	2	2	100	2	100	2	100
Conduits	Phase Created	2	2	100	2	100	2	100
Conduits	Service Type	2	2	100	0	0	2	100
Conduits	Size	2	2	100	2	100	2	100
Conduits	Top Elevation	2	0	0	0	0	0	0
Conduits	UniFormat	2	0	0	0	0	0	0
Curtain Panels	Area	4394	4394	100	4394	100	4394	100
Curtain Panels	Computation Height	4394	4394	100	4394	100	4394	100
Curtain Panels	Construction Sequence	4394	0	0	0	0	0	0
Curtain Panels	Construction Type	4394	3479	79.17615	0	0	3479	79.17614929
Curtain Panels	Keynote	4394	3479	79.17615	0	0	3479	79.17614929
Curtain Panels	MasterFormat	4394	0	0	0	0	0	0
Curtain Panels	Offset	4394	4394	100	4394	100	4394	100
Curtain Panels	Phase Created	4394	4394	100	4394	100	4394	100
Curtain Panels	Thickness	4394	4394	100	4394	100	4394	100
Curtain Panels	UniFormat	4394	0	0	0	0	0	0
Curtain Panels	Volume	4394	4394	100	4394	100	4394	100
Curtain Panels	Width	4394	4394	100	4394	100	4394	100
Curtain Wall Mullions	Angle	6965	6959	99.91385	6959	99.91385	6959	99.91385499
Curtain Wall Mullions	Area	6965	6965	100	6965	100	6965	100
Curtain Wall Mullions	Computation Height	6965	6965	100	6965	100	6965	100
Curtain Wall Mullions	Construction Sequence	6965	0	0	0	0	0	0
Curtain Wall Mullions	Keynote	6965	6965	100	615	8.829864	6965	100
Curtain Wall Mullions	Length	6965	6965	100	6965	100	6965	100
Curtain Wall Mullions	MasterFormat	6965	0	0	0	0	0	0
Curtain Wall Mullions	Offset	6965	6965	100	6965	100	6965	100
Curtain Wall Mullions	Phase Created	6965	6965	100	6965	100	6965	100
Curtain Wall Mullions	Thickness	6965	6965	100	6965	100	6965	100
Curtain Wall Mullions	UniFormat	6965	0	0	0	0	0	0
Curtain Wall Mullions	Volume	6965	6965	100	6965	100	6965	100
Curtain Walls	Angle	1019	1016	99.70559	1016	99.70559	1016	99.70559372
Curtain Walls	Area	1019	1019	100	1019	100	1019	100
Curtain Walls	Construction Sequence	1019	0	0	0	0	0	0
Curtain Walls	Function	1019	1019	100	1019	100	0	0
Curtain Walls	Join Condition	1019	1019	100	1019	100	0	0
Curtain Walls	Keynote	1019	1019	100	331	32.48283	1019	100
Curtain Walls	Length	1019	1019	100	1019	100	1019	100
Curtain Walls	MasterFormat	1019	0	0	0	0	0	0
Curtain Walls	Number	1019	0	0	0	0	0	0
Curtain Walls	Offset	1019	1019	100	1019	100	1019	100
Curtain Walls	Phase Created	1019	1019	100	1019	100	1019	100
Curtain Walls	Spacing	1019	1019	100	1019	100	1019	100
Curtain Walls	Top Offset	1019	106	10.40236	106	10.40236	106	10.40235525
Curtain Walls	Unconnected Height	1019	1019	100	1019	100	1019	100
Curtain Walls	UniFormat	1019	0	0	0	0	0	0
Doors	Area	425	425	100	425	100	425	100

Appendix B: Model Data Enrichment for Project A

			BEXEL Added	BEXEL Added
			Text	Text
Category	IFC System ObjectType	IFC Entity	Uniformat 2010 Code	Uniformat 2010 Description
Air Terminals			D3050.50	HVAC Air Distribution
Air Terminals	Supply Air | Supply Air		D3060.10	Supply Air
Air Terminals	Return Air | Return Air		D3060.20	Return Air
Air Terminals	Exhaust Air | Exhaust Air		D3060.30	Exhaust Air
Air Terminals	Outside Air |Outside Air		D3060.40	Outside Air
Cable Tray Fittings			D5020.30	Power Distribution
Cable Trays			D5020.30	Power Distribution
Communication Devices			D6030.50	Electronic Digital Systems
Conduit Fittings			D5030.10	Branch Wiring System
Coverings			C2010.30	Wall Finishies-Coverings
Coverings			C2010.30	Wall Finishies-Coverings
Conduits			D5030.10	Branch Wiring System
Data Devices			D6010.20	Data Communications Hardware
Duct Accessories			D3050.50	HVAC Air Distribution
Duct Accessories	Supply Air | Supply Air		D3060.10	Supply Air
Duct Accessories	Return Air | Return Air		D3060.20	Return Air
Duct Accessories	Exhaust Air | Exhaust Air		D3060.30	Exhaust Air
Duct Accessories	Outside Air | Outside Air		D3060.40	Outside Air
Duct Fittings			D3050.50	HVAC Air Distribution
Duct Fittings	Supply Air | Supply Air		D3060.10	Supply Air
Duct Fittings	Return Air | Return Air		D3060.20	Return Air
Duct Fittings	Exhaust Air | Exhaust Air		D3060.30	Exhaust Air
Ducts			D3050.50	HVAC Air Distribution
Ducts	Supply Air | Supply Air		D3060.10	Supply Air
Ducts	Return Air | Return Air		D3060.20	Return Air
Ducts	Exhaust Air | Exhaust Air		D3060.30	Exhaust Air
Electrical Equipment			D5020.10	Electrical Service
Electrical Fixtures			D5030.50	Wiring Devices
Fire Alarm Devices			D7050.10	Fire Detection and Alarm
Flex Ducts			D3050.50	HVAC Air Distribution
Flex Ducts	Supply Air | Supply Air		D3060.10	Supply Air
Flex Ducts	Return Air | Return Air		D3060.20	Return Air
Flex Ducts	Exhaust Air | Exhaust Air		D3060.30	Exhaust Air
Flex Pipes			D2010.40	Domestic Water Piping
Flex Pipes	Domestic Hot Water | Domestic Hot Water		D2010.40	Domestic Water Piping
Flex Pipes	Domestic Cold Water | Domestic Cold Water		D2010.40	Domestic Water Piping
Flex Pipes	Sanitary | Sanitary		D2020.30	Sanitary Sewerage Piping
Lighting Devices			D5040.10	Lighting Control
Insulations			D3050.50	Air Distribution Systems
Insulations	Exhaust Air | Exhaust Air		D3060.30	Exhaust Ventilation Systems
Insulations	Return Air | Return Air		D3060.20	Return Air Distribution Systems
Insulations	Supply Air | Supply Air		D3060.10	Supply Air Distribution Systems
Lighting Fixtures			D5040.50	Lighting Fixtures
Mechanical Equipment			D3050.90	Facility Distribution Systems Supplementary
Mechanical Equipment	Domestic Hot Water | Domestic Hot Water		D2010.20	Domestic Water Equipment
Mechanical Equipment	Domestic Cold Water | Domestic Cold Water		D2010.20	Domestic Water Equipment
Mechanical Equipment	Sanitary | Sanitary		D2020.10	Sanitary Sewerage Equipment
Mechanical Equipment	Fire Protection Wet | Fire Protection Wet		D4010.90	Fire Suppression Supplementary Componen
Mechanical Equipment	Hydronic_Return | Hydronic_Return		D3060.90	Ventilation Supplementary Components
Mechanical Equipment	Hydronic_Supply | Hydronic_Supply		D3060.90	Ventilation Supplementary Components
Pipe Accessories			D2010.90	Domestic Water Distribution Supplementary
Pipe Fittings			D2010.40	Domestic Water Piping
Pipe Fittings	Domestic Hot Water | Domestic Hot Water		D2010.40	Domestic Water Piping
Pipe Fittings	Domestic Cold Water | Domestic Cold Water		D2010.40	Domestic Water Piping
Pipe Fittings	Sanitary | Sanitary		D2020.30	Sanitary Sewerage Piping
Pipe Fittings	Fire Protection Wet | Fire Protection Wet		D4010.10	Water-Based Fire-Suppression
Pipe Fittings	Hydronic_Return | Hydronic_Return		D3050.10	Facility Hydronic Distribution
Pipe Fittings	Hydronic_Supply | Hydronic_Supply		D3050.10	Facility Hydronic Distribution
Pipe Fittings	Fire Protection Dry | Fire Protection Dry		D4010.50	Fire-Extinguishing
Pipes			D2010.40	Domestic Water Piping
Pipes	Domestic Hot Water | Domestic Hot Water		D2010.40	Domestic Water Piping
Pipes	Domestic Cold Water | Domestic Cold Water		D2010.40	Domestic Water Piping
Pipes	Sanitary | Sanitary		D2020.30	Sanitary Sewerage Piping
Pipes	Fire Protection Wet | Fire Protection Wet		D4010.10	Water-Based Fire-Suppression
Pipes	Hydronic_Return | Hydronic_Return		D3050.10	Facility Hydronic Distribution
Pipes	Hydronic_Supply | Hydronic_Supply		D3050.10	Facility Hydronic Distribution
Pipes	Fire Protection Dry | Fire Protection Dry		D4010.50	Fire-Extinguishing
Plumbing Fixtures			D2010.60	Plumbing Fixtures

			BEXEL Added	BEXEL Added
			Text	Text
Category	IFC System ObjectType	IFC Entity	Uniformat 2010 Code	Uniformat 2010 Description
Plumbing Fixtures	Domestic Hot Water | Domestic Hot Water		D2010.60	Plumbing Fixtures
Plumbing Fixtures	Domestic Cold Water | Domestic Cold Water		D2010.60	Plumbing Fixtures
Plumbing Fixtures	Sanitary | Sanitary		D2020.10	Sanitary Sewerage Equipment
Plumbing Fixtures	Fire Protection Wet | Fire Protection Wet		D4010.10	Water-Based Fire-Suppression
Plumbing Fixtures	Fire Protection Dry | Fire Protection Dry		D4010.50	Fire-Extinguishing
Security Devices			D7030.50	Electronic Personal Protection
Sprinklers			D4010.50	Fire-Extinguishing
Sprinklers	Fire Protection Wet | Fire Protection Wet		D4010.10	Water-Based Fire-Suppression
Sprinklers	Fire Protection Dry | Fire Protection Dry		D4010.50	Fire-Extinguishing
Fire Protection			D4010.50	Fire-Extinguishing
Fire Protection	Fire Protection Wet | Fire Protection Wet		D4010.10	Water-Based Fire-Suppression
Transport			D1010.10	Passanger Elevator
Transport			D1010.10	Passanger Elevator
Fire Protection	Fire Protection Dry | Fire Protection Dry		D4010.50	Fire-Extinguishing
Telephone Devices			D6020.10	Voice Communications Switching and Routi
Flow Terminals			D2010.60	Plumbing Fixtures
Wires			D5040.20	Branch Wiring for Lighting
Casework			E2010.30	Casework
Ceilings			C1070.20	Suspended Plaster and Gypsum Board Ceili
Columns			B2010.80	Exterior Wall Supplementary Components
Curtain Panels			B2020.30	Exterior Window Wall
Curtain Wall Mullions			B2020.30	Exterior Window Wall
Members			B1020.30	Canopy Construction
Doors			B2050.90	Exterior Door Supplementary Components
Slabs			B1010.20	Upper Floor Framing - Systems
Slabs			C2030.10	Floor Toppings & Coatings
Furniture			E2050.30	Furniture
Furniture Systems			E2050.30	Furniture
Parkings			G2020.40	Parking Lot Appurtenances
Planting			G2080.30	Plants
Railings			B1080.50	Stair Railings
Ramps			B1010.50	Ramps
Roads			G2010.10	Roadway Pavement
Roofs			B1020.20	Roof Decks, Slabs, and Sheathing
Sites			G2080.80	Landscaping Activities
Stairs			B1080.10	Stair Construction
Walls			B2010.20	Exterior Wall Construction
Walls			B2010.20	Exterior Wall Construction
Walls			C1010.10	Interior Fixed Partitions
Windows			B2020.10	Exterior Operating Windows
Structural Columns			B1010.90	Floor Construction Supplementary Compon
Structural Columns			A1020.15	Bored Piles
Structural Foundations			A1020.70	Pile Caps
Structural Framing			B1010.10	Floor Structural Frame
Beams			B1020.30	Canopy Construction
Specialty Equipment			E1030.40	Maintenance Equipment
Wall Sweeps			B2010.80	Exterior Wall Supplementary Components
Valves			D2010.60	Plumbing Fixtures
Valves	Domestic Hot Water | Domestic Hot Water		D2010.60	Plumbing Fixtures
Valves	Domestic Cold Water | Domestic Cold Water		D2010.60	Plumbing Fixtures
Valves	Sanitary | Sanitary		D2020.10	Sanitary Sewerage Equipment
Valves	Fire Protection Wet | Fire Protection Wet		D4010.10	Water-Based Fire-Suppression
Valves	Fire Protection Dry | Fire Protection Dry		D4010.50	Fire-Extinguishing
Generic Models		IfcWall	B2010.20	Exterior Wall Construction
Parts		IfcSlab	B1010.20	Upper Floor Framing - Systems
Parts		IfcWall	B2010.20	Exterior Wall Construction

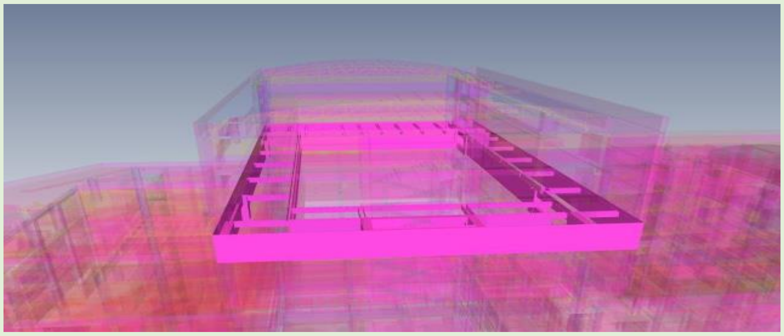
Appendix C: Clash Detection Reports for Project A

Job N	Job T	Name	Source	Storey:1	Cate	Family:1	Sourc	Storey:2
Job 1	Hard	Clash1	1017559	FORTH FLOOR PLAN VOLUME ONE	Walls	Basic - IN_GYPSUM-PLASTERING_25M	589304	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash2	1017559	FORTH FLOOR PLAN VOLUME ONE	Walls	Basic - IN_GYPSUM-PLASTERING_25M	589303	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash3	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	642871	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash4	485776	FORTH FLOOR PLAN VOLUME ONE	Slabs	IN_ARMSTRONG VINYL VARIT FLOORI	589304	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash5	485776	FORTH FLOOR PLAN VOLUME ONE	Slabs	IN_ARMSTRONG VINYL VARIT FLOORI	589303	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash6	1012634	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	589304	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash7	1011220	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	589303	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash8	1012634	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	589303	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash9	1318322	THIRD FLOOR PLAN	Spaces	Rooms	589303	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash10	1017491	FORTH FLOOR PLAN VOLUME ONE	Walls	Basic - IN_GYPSUM-PLASTERING_25M	659907	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash11	485805	FORTH FLOOR PLAN VOLUME ONE	Slabs	IN_POLISHED MARBLE TILE_600x600N	659907	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash12	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	659907	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash13	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	642870	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash14	1317316	THIRD FLOOR PLAN	Spaces	Rooms	659907	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash15	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	642861	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash16	853215	MEZZANIN FLOOR PLAN	Spaces	Rooms	582606	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash17	853215	MEZZANIN FLOOR PLAN	Spaces	Rooms	568439	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash18	853215	MEZZANIN FLOOR PLAN	Spaces	Rooms	582372	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash19	852391	MEZZANIN FLOOR PLAN	Spaces	Rooms	565775	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash20	852391	MEZZANIN FLOOR PLAN	Spaces	Rooms	565774	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash21	853215	MEZZANIN FLOOR PLAN	Spaces	Rooms	565775	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash22	853215	MEZZANIN FLOOR PLAN	Spaces	Rooms	655423	MEZZANIN FLOOR PLAN
Job 1	Hard	Clash23	932182	THIRD FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	579935	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash24	932182	THIRD FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	579934	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash25	932214	THIRD FLOOR PLAN VOLUME ONE	Walls	Basic - IN_GYPSUM-PLASTERING_25M	579935	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash26	484421	THIRD FLOOR PLAN	Slabs	IN_ARMSTRONG VINYL VARIT FLOORI	579934	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash27	484421	THIRD FLOOR PLAN	Slabs	IN_ARMSTRONG VINYL VARIT FLOORI	579935	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash28	620744	THIRD FLOOR PLAN VOLUME ONE	Ceiling:	Soff_PLS_25-MM	579935	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash29	620744	THIRD FLOOR PLAN VOLUME ONE	Ceiling:	Soff_PLS_25-MM	579934	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash30	635277	THIRD FLOOR PLAN VOLUME ONE	Ceiling:	DECORATIVE-CELLING_600 x 600mm	579935	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash31	1317344	THIRD FLOOR PLAN	Spaces	Rooms	579934	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash32	1317344	THIRD FLOOR PLAN	Spaces	Rooms	579935	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash33	931462	THIRD FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	658700	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash34	484395	THIRD FLOOR PLAN	Slabs	IN_POLISHED MARBLE TILE_600x600N	658700	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash35	1317316	THIRD FLOOR PLAN	Spaces	Rooms	658700	THIRD FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash36	1011220	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	593199	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash37	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	642885	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash38	1012634	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	593199	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash39	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	642886	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash40	1015213	FIFTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	593199	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash41	1012634	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	593354	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash42	1064161	FIFTH FLOOR PLAN VOLUME ONE	Walls	Basic - IN_GYPSUM-PLASTERING_25M	661613	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash43	486449	FIFTH FLOOR PLAN VOLUME ONE	Slabs	IN_POLISHED MARBLE TILE_600x600N	661613	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash44	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	661613	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash45	1015199	FIFTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	661613	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash46	1010245	FORTH FLOOR PLAN VOLUME ONE	Spaces	Rooms	642876	FIFTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash47	772440	GROUND FLOOR PLAN	Spaces	Rooms	580813	GROUND FLOOR PLAN
Job 1	Hard	Clash48	772440	GROUND FLOOR PLAN	Spaces	Rooms	657594	GROUND FLOOR PLAN
Job 1	Hard	Clash49	772440	GROUND FLOOR PLAN	Spaces	Rooms	657915	GROUND FLOOR PLAN
Job 1	Hard	Clash50	772440	GROUND FLOOR PLAN	Spaces	Rooms	657190	GROUND FLOOR PLAN
Job 1	Hard	Clash51	465354	GROUND FLOOR PLAN	Slabs	IN_SMOOTH CEMENT SCREED WITH E	581264	GROUND FLOOR PLAN
Job 1	Hard	Clash52	772440	GROUND FLOOR PLAN	Spaces	Rooms	581264	GROUND FLOOR PLAN
Job 1	Hard	Clash53	772440	GROUND FLOOR PLAN	Spaces	Rooms	651662	GROUND FLOOR PLAN
Job 1	Hard	Clash54	831765	FIRST FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	583236	FIRST FLOOR PLAN
Job 1	Hard	Clash55	831765	FIRST FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	582545	FIRST FLOOR PLAN
Job 1	Hard	Clash56	858542	FIRST FLOOR PLAN	Spaces	Rooms	655455	FIRST FLOOR PLAN
Job 1	Hard	Clash57	656515	FORTH FLOOR PLAN VOLUME ONE	Ceiling:	DECORATIVE-CELLING_600 x 600mm	589304	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash58	656515	FORTH FLOOR PLAN VOLUME ONE	Ceiling:	DECORATIVE-CELLING_600 x 600mm	589303	FORTH FLOOR PLAN VOLUME ONE
Job 1	Hard	Clash59	891489	SECOND FLOOR PLAN	Spaces	Rooms	658362	SECOND FLOOR PLAN
Job 2	Hard	Clash1	481373	SECOND FLOOR PLAN	Walls	Basic - IN_HCB_150MM	4E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash2	481383	SECOND FLOOR PLAN	Walls	Basic - IN_HCB_150MM	3E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash3	863424	SECOND FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	4E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash4	914722	SECOND FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	4E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash5	915031	SECOND FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	4E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash6	915672	SECOND FLOOR PLAN	Walls	Basic - IN_GYPSUM-PLASTERING_25M	3E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash7	481788	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash8	481807	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash9	481807	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash10	481877	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash11	481877	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash12	481877	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash13	481877	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash14	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	3E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash15	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	4E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash16	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	4E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash17	1300306	SECOND FLOOR PLAN	Curtain	Rectangular Mullion - 50 x 100mm	4E+06	SECOND FLOOR PLAN
Job 2	Hard	Clash18	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	4E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash19	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	4E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash20	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	4E+06	FIRST FLOOR PLAN
Job 2	Hard	Clash21	482036	SECOND FLOOR PLAN	Slabs	IN_POLYPROPYLENE-WOVEN+ FLEECE	4E+06	FIRST FLOOR PLAN

Cate	Family:2	Storey	Distance	Export Date
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.050 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.006 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.079 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.100 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.079 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.092 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FORTH FLOOR PLAN VOLUME ONE	-0.013 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FORTH FLOOR PLAN VOLUME ONE	-0.013 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FORTH FLOOR PLAN VOLUME ONE	-0.013 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.050 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	THIRD FLOOR PLAN	-0.013 m	06/03/2025 09:44
Slabs	THREASHHOLD_GRANITE	FORTH FLOOR PLAN VOLUME ONE	-0.050 m	06/03/2025 09:44
Walls	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_I	MEZZANIN FLOOR PLAN	-0.025 m	06/03/2025 09:44
Walls	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_I	MEZZANIN FLOOR PLAN	-0.600 m	06/03/2025 09:44
Slabs	IN_GYPSUM SOFIT PLASTERING_50MM	MEZZANIN FLOOR PLAN	-0.466 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	MEZZANIN FLOOR PLAN	-0.100 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	MEZZANIN FLOOR PLAN	-0.130 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	MEZZANIN FLOOR PLAN	-0.100 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	MEZZANIN FLOOR PLAN	-0.086 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.104 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	THIRD FLOOR PLAN	-0.104 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	THIRD FLOOR PLAN	-0.013 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	THIRD FLOOR PLAN	-0.013 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	THIRD FLOOR PLAN	-0.013 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.010 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.050 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.079 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.050 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FIFTH FLOOR PLAN VOLUME ONE	-0.100 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.079 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FIFTH FLOOR PLAN VOLUME ONE	0.000 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FIFTH FLOOR PLAN VOLUME ONE	-0.010 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FORTH FLOOR PLAN VOLUME ONE	-0.013 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FIFTH FLOOR PLAN VOLUME ONE	-0.010 m	06/03/2025 09:44
Slabs	THREASHHOLD_GRANITE	FORTH FLOOR PLAN VOLUME ONE	-0.150 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	GROUND FLOOR PLAN	-0.086 m	06/03/2025 09:44
Walls	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_I	GROUND FLOOR PLAN	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_I	GROUND FLOOR PLAN	-0.004 m	06/03/2025 09:44
Ceilings	Soff_PLS_25-MM - (3;NNTP_OVD_V1_XX_M3_A_109_detached;6	GROUND FLOOR PLAN	-0.004 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	GROUND FLOOR PLAN	-0.010 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	GROUND FLOOR PLAN	-0.003 m	06/03/2025 09:44
Slabs	THREASHHOLD_GRANITE	GROUND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Walls	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_I	FIRST FLOOR PLAN	-0.017 m	06/03/2025 09:44
Walls	Basic - IN_GYPSUM-PLASTERING_25MM - (3;NNTP_OVD_V1_XX_I	FIRST FLOOR PLAN	-0.236 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	FIRST FLOOR PLAN	-0.026 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Walls	Basic - IN_HCB_200MM - (3;NNTP_OVD_V1_XX_M3_A_109_detac	FORTH FLOOR PLAN VOLUME ONE	-0.004 m	06/03/2025 09:44
Doors	IN_SINGLE-FIRE-RATED_T30-DOOR - IN_SNG-FR_T-30_STL-900x2	SECOND FLOOR PLAN	-0.026 m	06/03/2025 09:44
Electric	M_Lighting and Appliance Panelboard - 208V MLO - 20A/3P	SECOND FLOOR PLAN	-0.055 m	06/03/2025 09:44
Lighting	63513 - type-6,RZB.451068 580lm with LED 24W lamp.	SECOND FLOOR PLAN	0.000 m	06/03/2025 09:44
Electric	M_Lighting and Appliance Panelboard - 208V MLO - 20A/3P	SECOND FLOOR PLAN	-0.055 m	06/03/2025 09:44
Spaces	Spaces	SECOND FLOOR PLAN	-0.113 m	06/03/2025 09:44
Spaces	Spaces	SECOND FLOOR PLAN	-0.323 m	06/03/2025 09:44
Lighting	EAE_NETALED_SA_17W - Standart	SECOND FLOOR PLAN	-0.067 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Lighting	Emergency Wall Light - 120V-type-E,RZB 671707.002, 4000lm for 3	SECOND FLOOR PLAN	-0.062 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44
Electric	Electrical-Box_FSR_FL700 - One data-RJ-45,one tele-RJ-11 and twi	SECOND FLOOR PLAN	-0.050 m	06/03/2025 09:44

Appendix D: Quantity Takeoff Reports of Project A

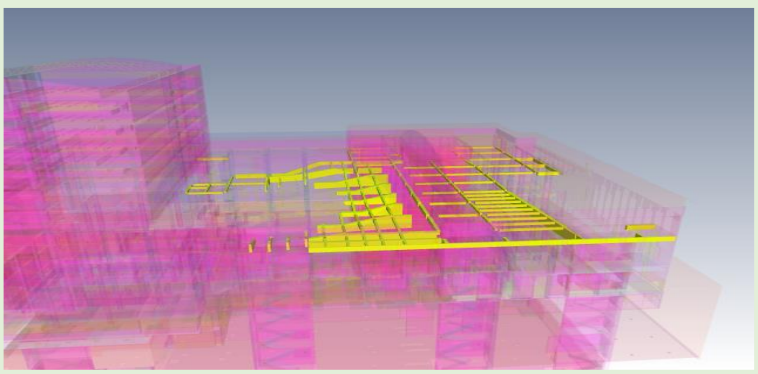
Styled Reports



Exterior Wall Construction

m²	2,069.95
m³	147.86
	199.00

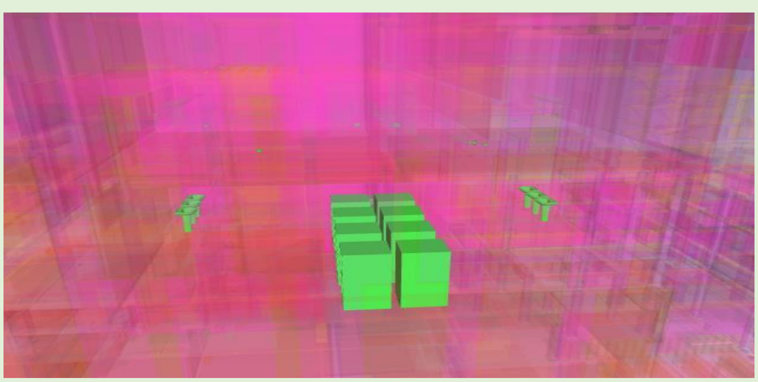
FIFTH FLOOR PLAN



Canopy Construction

m³	223.13
	118.00

FIFTH FLOOR PLAN VOLUME ONE



Plumbing Fixtures

Count	50.00

Generated QTO in Excel Format

Outline Leve	Code	Name	Description	Element Count	Automatic Quantity
1	QTO C - Created on 3/9/2025 10:56:0(	QTO C - Created on 3/9/2025 10:56:00 AM		23915	
1.1	QTO C	QTO C		23915	
1.1.1	33710 - 33710 ALOHA Brown ceiling fa	33710 - 33710 ALOHA Brown ceiling fan		1	
1.1.1.0	FARO_Brown(1)	FARO_Brown(1)	FARO_Brown(1)	1	0.636
1.1.1.0	FARO_Dark_wood	FARO_Dark_wood	FARO_Dark_wood	1	0.636
1.1.2	3Mx1.9M-T0801 - Workbench - 3Mx1.	3Mx1.9M-T0801 - Workbench - 3Mx1.9M-T0801 - Workbench		10	
1.1.2.0	Laminate, Ivory, Matte	Laminate, Ivory, Matte	Laminate, Ivory, Matte	10	199.673
1.1.2.0	Steel, Paint Finish, Dark Gray	Steel, Paint Finish, Dark Gray	Steel, Paint Finish, Dark	10	199.673
1.1.3	63513 - typ-6,RZB.451068 580lm with	63513 - typ-6,RZB.451068 580lm with LED 24W lamp.		63	
1.1.3.0	FARO_Cromo	FARO_Cromo	FARO_Cromo	63	5.736
1.1.3.0	FARO_Int_Structure	FARO_Int_Structure	FARO_Int_Structure	63	5.736
1.1.3.0	FARO_White_translucide	FARO_White_translucide	FARO_White_translucide	63	5.736
1.1.4	63513 - type-6,RZB.451068 580lm wit	63513 - type-6,RZB.451068 580lm with LED 24W lamp.		90	
1.1.4.0	FARO_Cromo	FARO_Cromo	FARO_Cromo	90	5.079
1.1.4.0	FARO_Int_Structure	FARO_Int_Structure	FARO_Int_Structure	90	5.079
1.1.4.0	FARO_White_translucide	FARO_White_translucide	FARO_White_translucide	90	5.079
1.1.5	64128-3L - Type-9, Transparent penda	64128-3L - Type-9, Transparent pendant lamp 3 sets		24	
1.1.5.0	FARO_Black Paint	FARO_Black Paint	FARO_Black Paint	24	60.576
1.1.5.0	FARO_Glass	FARO_Glass	FARO_Glass	24	60.576
1.1.5.0	FARO_Int_Structure	FARO_Int_Structure	FARO_Int_Structure	24	60.576
1.1.6	64501 - typ-10,RZB.901433.002.1 640	64501 - typ-10,RZB.901433.002.1 640lm with LED 9W lamp.64501 NAOS Beige/Terracotta pendant lamp Ø400		150	
1.1.6.0	FARO_Beige	FARO_Beige	FARO_Beige	150	58.312
1.1.6.0	FARO_Int_Structure	FARO_Int_Structure	FARO_Int_Structure	150	58.312
1.1.6.0	FARO_Terracotta	FARO_Terracotta	FARO_Terracotta	150	58.312
1.1.6.0	FARO_White	FARO_White	FARO_White	150	58.312
1.1.6.0	FARO_White_translucide	FARO_White_translucide	FARO_White_translucide	150	58.312
1.1.7	Allsteel_Acuity_Office_Chair_8186 - A	Allsteel_Acuity_Office_Chair_8186 -		19	
1.1.7.0	Acuity Black Plastic	Acuity Black Plastic	Acuity Black Plastic	19	25.569
1.1.7.0	Acuity Carrier- Graphite	Acuity Carrier- Graphite	Acuity Carrier- Graphite	19	25.569
1.1.7.0	Acuity Finish- Polished Aluminum	Acuity Finish- Polished Aluminum	Acuity Finish- Polished	19	25.569
1.1.7.0	Acuity Mesh- Dusk	Acuity Mesh- Dusk	Acuity Mesh- Dusk	19	25.569
1.1.7.0	Acuity Upholstery Leather- Black	Acuity Upholstery Leather- Black	Acuity Upholstery Leather-	19	25.569
1.1.8	Armstrong Canopy Ceiling 600x600x1!	Armstrong Canopy Ceiling 600x600x15		2	
1.1.8.0	Mineral-Armstrong_Ceilings-BP770M4	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-600x600mm	Mineral-Armstrong_Ceilings-	2	390.356
1.1.9	Armstrong Ceiling 600x600x15	Armstrong Ceiling 600x600x15		1	
1.1.9.0	Mineral-Armstrong_Ceilings-BP770M4	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-600x600mm	Mineral-Armstrong_Ceilings-	1	107.120
1.1.10	Armstrong Ceiling (Parafon Hygien) 30(	Armstrong Ceiling (Parafon Hygien) 300x300x15		9	
1.1.10.0	Mineral-Armstrong_Ceilings-BP770M4	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-300x300mm	Mineral-Armstrong_Ceilings-	9	317.356
1.1.11	Armstrong Ceiling (Ultima) 600x600x1!	Armstrong Ceiling (Ultima) 600x600x15		1	
1.1.11.0	Mineral-Armstrong_Ceilings-BP770M4	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-600x600mm	Mineral-Armstrong_Ceilings-	1	30.281
1.1.12	ARMSTRONG CEILING 600 x 600mm	ARMSTRONG CEILING 600 x 600mm		22	
1.1.12.0	Ceiling Tile 600 x 600	Ceiling Tile 600 x 600	Ceiling Tile 600 x 600	22	1,077.344
1.1.12.0	Default	Default	Default	22	1,077.344
1.1.13	assmann_cubas_metallregal_1000x44(	assmann_cubas_metallregal_1000x440x1570 - ASSMANN BÜROMÖBEL GMBH & CO. KG Cubas Metallregal 1000x440x1570		7	
1.1.13.0	askuswa50284f8	askuswa50284f8	askuswa50284f8	7	53.226
1.1.13.0	asmeswf61042d1	asmeswf61042d1	asmeswf61042d1	7	53.226
1.1.13.0	asplef3c90a4b2	asplef3c90a4b2	asplef3c90a4b2	7	53.226
1.1.13.0	aspltar8a3c2154	aspltar8a3c2154	aspltar8a3c2154	7	53.226
1.1.13.0	aspltfg86ff57cc	aspltfg86ff57cc	aspltfg86ff57cc	7	53.226
1.1.13.0	aspltkg0e21f942	aspltkg0e21f942	aspltkg0e21f942	7	53.226
1.1.13.0	aspltlg8365e3b7	aspltlg8365e3b7	aspltlg8365e3b7	7	53.226
1.1.14	Basic - EX_100-mm_CONC	Basic - EX_100-mm_CONC		5	
1.1.14.0	Concrete - Cast-in-Place Concrete	Concrete - Cast-in-Place Concrete	Concrete - Cast-in-Place	5	228.132
1.1.15	Basic - EX_200-mm_HCB	Basic - EX_200-mm_HCB		138	
1.1.15.0	HCB	HCB	HCB	138	5,102.362
1.1.16	Basic - EX_25-mm_PLS-resess	Basic - EX_25-mm_PLS-resess		2	
1.1.16.0	Cement Plasterresess	Cement Plasterresess	Cement Plasterresess	2	167.624
1.1.17	Basic - EX_CLD_GRA_25-mm	Basic - EX_CLD_GRA_25-mm		7	
1.1.17.0	Tile - 600 x 600mm Granite	Tile - 600 x 600mm Granite	Tile - 600 x 600mm Granite	7	92.060
1.1.18	Basic - EX_HCB_200MM	Basic - EX_HCB_200MM		19	
1.1.18.0	Nttp_Hcb_200mm	Nttp_Hcb_200mm	Nttp_Hcb_200mm	19	373.873
1.1.19	Basic - IN _HCB_100MM	Basic - IN _HCB_100MM		62	
1.1.19.0	Nttp_Hcb_100mm	Nttp_Hcb_100mm	Nttp_Hcb_100mm	62	391.955
1.1.20	Basic - IN_100-mm_DIA PARTITION W	Basic - IN_100-mm_DIA PARTITION WALLS		4	
1.1.20.0	Gypsum Wall Board	Gypsum Wall Board	Gypsum Wall Board	4	138.105
1.1.21	Basic - IN_200-mm_DIA PARTITION W	Basic - IN_200-mm_DIA PARTITION WALLS 2		6	
1.1.21.0	Gypsum Wall Board	Gypsum Wall Board	Gypsum Wall Board	6	97.729

Appendix D: Cost Assignment based on QTO for Project A

Outline Lev	Code	Name	Element	Automatic Q	Quantit	Quantity	Quant	Material Sup	Labor Supple	Equipment S
1	new based - Created on 3/15/2025 12:53:24 PM	new based - Created on 3/15/2025 12:53:24 PM	20534							
1.1	new based	new based	20534							
1.1.1	Ceilings	Ceilings	61							
1.1.1.0	Default	Default	48	5,293.975	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.1.0	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-300x300mm	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-300x300mm	9	317.356	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.1.0	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-600x600mm	Mineral-Armstrong_Ceilings-BP770M4B-Cortega-Board-600x600mm	4	527.757	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.2	Communication Devices	Communication Devices	1							
1.1.2.0	Metal - Crestron - Black	Metal - Crestron - Black	1	0.597	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.3	Curtain Panels	Curtain Panels	3197							
1.1.3.0	Glass	Glass	3197	5,014.534	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.4	Curtain Wall Mullions	Curtain Wall Mullions	6965							
1.1.4.0	Aluminium	Aluminium	621	218.672	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.4.0	Aluminum	Aluminum	6344	1,432.688	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.5	Electrical Fixtures	Electrical Fixtures	65							
1.1.5.0	Material and Finish as Specified in 26 27 26	Material and Finish as Specified in 26 27 26	65	19.985	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.6	Fire Alarm Devices	Fire Alarm Devices	159							
1.1.6.0	Comelit - PC - Bianco trasparente	Comelit - PC - Bianco trasparente	136	4.306	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.6.0	White Plastic	White Plastic	23	0.663	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.7	Furniture	Furniture	767							
1.1.7.0	A GREY COUCH	A GREY COUCH	11	119.495	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.7.0	Isomi_Concrete_LightGrey	Isomi_Concrete_LightGrey	13	24.530	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.7.0	Laminate, Black(1)	Laminate, Black(1)	3	11.731	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.7.0	Metal - Chrome	Metal - Chrome	35	66.545	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.7.0	Paint - White	Paint - White	600	3,281.507	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.7.0	White	White	105	667.989	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.8	Lighting Fixtures	Lighting Fixtures	1519							
1.1.8.0	Glass, Frosted	Glass, Frosted	1216	625.664	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.8.0	Glass, White, High Luminance	Glass, White, High Luminance	33	5.081	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.8.0	Plastic - Blue	Plastic - Blue	1	0.278	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.8.0	Steel, Paint Finish, Ivory, Glossy	Steel, Paint Finish, Ivory, Glossy	291	29.443	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.9	Masses	Masses	1							
1.1.9.0	Default Form	Default Form	1	5.969	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00

Outline Lev	Code	Name	Element	Automatic Q	Quantit	Quantity	Quant	Material Sup	Labor Supple	Equipment S
1.1.10	Parkings	Parkings	204							
1.1.10.0	Parking Stripe	Parking Stripe	204	273.634	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.11	Pipes	Pipes	3104							
1.1.11.0	Polyvinyl Chloride - Rigid	Polyvinyl Chloride - Rigid	3104	716.703	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.12	Plumbing Fixtures	Plumbing Fixtures	746							
1.1.12.0	hilltake tank	hilltake tank	10	179.333	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.12.0	Metal-WATTS-Nickel Bronze	Metal-WATTS-Nickel Bronze	16	0.913	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.12.0	Plastic-WATTS-PVC	Plastic-WATTS-PVC	102	0.000	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.12.0	Porcelain - White	Porcelain - White	260	241.718	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.12.0	Vitreous China - TOTO - 01 Cotton	Vitreous China - TOTO - 01 Cotton	358	199.192	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.13	Sites	Sites	137							
1.1.13.0	Lauan, Meranti	Lauan, Meranti	3	40.153	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.13.0	Paint - White	Paint - White	134	18.942	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14	Slabs	Slabs	179							
1.1.14.0	Concrete - Sand/Cement Plaster	Concrete - Sand/Cement Plaster	2	169.048	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Default Floor	Default Floor	1	432.748	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Carpet Tile	Nttp_Carpet Tile	1	66.856	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Carpeting on smooth concrete finish	Nttp_Carpeting on smooth concrete finish	1	65.375	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Cement Screed	Nttp_Cement Screed	18	2,523.190	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Ceramic-Mosaic-Tiles_100x100mm	Nttp_Ceramic-Mosaic-Tiles_100x100mm	1	4.767	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_High quality Ceramic Mosic Tile_100x100mm	Nttp_High quality Ceramic Mosic Tile_100x100mm	3	588.568	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Non Slipery Porceline Tiles_600x600mm	Nttp_Non Slipery Porceline Tiles_600x600mm	10	161.226	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Polished Marble Tile_600x600mm	Nttp_Polished Marble Tile_600x600mm	16	1,350.264	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_POLYPROPYLENE WOVEN+FLEECE, DESSO - 200 x 200 - MM	Nttp_POLYPROPYLENE WOVEN+FLEECE, DESSO - 200 x 200 - MM	18	1,190.356	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Unglazed Ceramic Tiles_600x600mm	Nttp_Unglazed Ceramic Tiles_600x600mm	45	699.492	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Vinyl Composition Tile	Nttp_Vinyl Composition Tile	8	536.727	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp_Vinyl Sheet Flooring	Nttp_Vinyl Sheet Flooring	6	1,171.391	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Nttp-Granite Tile_600x600mm	Nttp-Granite Tile_600x600mm	2	8.972	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.14.0	Tile - 300 x 300mm Granite	Tile - 300 x 300mm Granite	47	31.965	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.15	Specialty Equipment	Specialty Equipment	8							
1.1.15.0	Metal Polished	Metal Polished	4	17.750	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.15.0	Steel - Madrax - Galvanized	Steel - Madrax - Galvanized	4	26.543	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16	Walls	Walls	3368							
1.1.16.0	Cement Plasterresess	Cement Plasterresess	2	167.624	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Concrete - Cast-in-Place Concrete	Concrete - Cast-in-Place Concrete	5	228.132	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Concrete, Cast-in-Place gray	Concrete, Cast-in-Place gray	8	0.007	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Default Roof	Default Roof	527	11,379.826	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Gypsum Wall Board	Gypsum Wall Board	10	235.834	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	HCB	HCB	143	5,108.849	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Nttp_Gypsum Plastering	Nttp_Gypsum Plastering	2197	10,917.956	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Nttp_Hcb_100mm	Nttp_Hcb_100mm	62	391.955	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Nttp_Hcb_150mm	Nttp_Hcb_150mm	112	1,671.755	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Nttp_Hcb_200mm	Nttp_Hcb_200mm	105	1,937.404	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Nttp_Marble 600x600MM	Nttp_Marble 600x600MM	53	270.492	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Nttp_quad-Panel - Mahogany	Nttp_quad-Panel - Mahogany	137	830.517	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.16.0	Tile - 600 x 600mm Granite	Tile - 600 x 600mm Granite	7	92.060	Area	m^2	[Area]	$ 8,000.00	$ 800.00	$ 500.00
1.1.17	Windows	Windows	53							