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Building Information Modeling (BIM) workflow and technological framework for building design - The case of Ethiopian Construction Design and Supervision Works Corporation - Building and Urban Design Sector

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BUILDING INFORMATION MODELING (BIM) WORKFLOW AND TECHNOLOGICAL FRAMEWORK FOR BUILDING DESIGN

THE CASE OF ETHIOPIAN CONSTRUCTION DESIGN AND SUPERVISION WORKS CORPORATION - BUILDING AND URBAN DESIGN SECTOR

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Declaration

I, the undersigned, hereby declare that this thesis is my original work and has not been presented in other universities and that all sources of material used under this thesis have been accordingly acknowledged following the scientific guidelines of the institute.

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Abstract

The construction industry plays a vital role in the development of any country, as it is responsible for constructing essential infrastructure projects that are necessary for societal and economic growth. However, the adoption of advanced technologies and workflows, such as BIM, remains relatively low in developing countries like Ethiopia. This can be attributed to various challenges, including resistance to change, high adoption costs, and the lack of government support. This study focuses on the implementation of BIM, its workflow and technological framework at the Ethiopian Construction Design and Supervision Works Corporation (ECDSWC). The objective is to study the BIM implementation on an active project within the company and develop a contextually appropriate BIM workflow and technological framework that aligns with the existing protocols at ECDSWC. The implementation and workflow of BIM encompasses areas such as training and education, data management, the technological framework, and collaboration among different departments within the organization.

To investigate these aspects, a case study approach is employed, observing and analyzing the operational and technical implementation of BIM at ECDSWC. Data collection involves interviews, questionnaires, observations, and document analysis conducted with the design participants of the CoESCoEM project. The research findings highlight that the adoption of BIM at ECDSWC has resulted in significant improvements in cross-disciplinary collaboration and communication. However, challenges arose due to the demanding project timeline, notable design complexities, the absence of a well-integrated BIM workflow, and the relative inexperience of the BIM team. These factors led to errors, shortcuts, technical issues, fragmented workflows, and omissions in the final project outcomes. The study further delves into the operational and technical aspects of BIM during the design process at ECDSWC, analyzing the existing design workflow to enhance efficiency and effectiveness through the utilization of BIM. Finally, the study developed a BIM workflow and technological framework to enhance BIM implementation by integrating it within the existing workflow in a manner that suits the specific context. Ultimately, this research aims to contribute to the existing knowledge base on BIM implementation as an emerging technology in Ethiopia's AEC industry.

Key Words: BIM implementation, ECDSEC, workflow

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Abbreviations

AEC – Architecture, Engineering and Construction

AIA - American Institute of Architects

AIM - Asset Information Modeling

AIR – Asset Information Requirements

BEP- BIM execution plan

BIM – Building information modeling

BM – BIM Manager

BSI - British Standards

CAD - Computer Aided Design

CDE - Common Data Environment

COBie – Construction Operations Building Information Exchange

CoESCoEM - Center of Excellence for Sustainable Construction Engineering & Management Administration Building

ECDSWC - Ethiopian Construction Design and Supervision Works Corporation (Building and Urban Design Sector)

CMI - Ethiopian Construction Project Management Institute

EIR – Exchange Information Requirements

FDRE - Federal Democratic Republic of Ethiopia

GDP – Gross Domestic Product

IFC - Industry Foundation Classes

IPD - Integrated Project Delivery

ISO - International Organizations for Standardization

LCC - Life Cycle Cost

MEP - Mechanical, electrical and plumbing engineering

MET - Model Execution Table

MoUDC - Ministry of Urban Development & Construction

NBIMS - National BIM Standards

OIR - Organizational Information Requirement

PM – Project Manager

ROI - Return on Investment

TT – Task team

VDC - Virtual Design and Construction

Chapter 1 - Introduction

1.1 Background of the study

The construction sector of the economy uses a variety of resources to create vital infrastructure projects for societal and economic growth (Hou, 2019). As a result, the industry contributes significantly to the development of the nation by building new factories, schools, health care facilities, sports and recreation centers, housing, roads, railways, airports, ports, power generation and distribution systems, telecommunications lines, and distribution systems, hydropower, irrigation, water supply, sewerage, etc., as well as expanding and developing existing economic and social infrastructure facilities (Hou, 2019).

As one of the fundamental sectors of a developing nation, the building sector directly contributes to enhancing both the quality of life in urban and rural regions. It is also a sector where a lot of inventions and scientific discoveries are being created, with the hope that they may eventually generate foreign revenue. Investment, which is spending cash to get products or services in return, yields noticeable advantages by boosting output and productivity (Al-Kodmany, 2012).

In the AEC industry, contracts, joint ventures, and other business modalities are used to create complicated interactions between clients, engineers, architects, consultants, contractors, different construction equipment and input suppliers, financial institutions, and surety institutions. However, these stakeholders' service delivery is still much behind what the market actually needs. Therefore, technical innovation and collaborative work environments have started to play a more important role in the AEC industry as a whole (Ruffle, 1986).

In industrialized nations, the building sector contributes 4–6% of GDP, while in poor nations, it makes up 4-12%. Its share of the GDP has even increased to 24% in some nations (Kniivilä, 2007). The construction industry is predicted to contribute 13% of the global GDP on average (Kniivilä, 2007). According to pertinent figures from the National Bank of Ethiopia, the construction industry's GDP contribution to the nation increased from 4.0% in 2001 to approximately 20% in 2017–18 (National Bank of Ethiopia, 2022).

Over the past ten years, Ethiopia's economy has grown tremendously as a result of its massive overall investment program. According to the National Bank of Ethiopia, the government made the highest investment since it spent more than 50% of its budget during the previous ten years on development capital. Banks are crucial to Ethiopia's construction industry, just like the government is in the industrial sector (National Bank of Ethiopia, 2022).

Ethiopia has long recognized how crucial it is to take action to boost the performance of the building sector. Along with its involvement in large-scale infrastructure development projects, the government has been working diligently to strengthen institutions’ and people resources' capabilities in the construction sector (National Bank of Ethiopia, 2022). However, these efforts have less long-lasting effects, and the performance of construction contract delivery is still well behind the required delivery requirements or industry norms (Ethiopian Construction Project Management Institute, 2019). Furthermore, despite the size and involvement of multinational construction firms, which were supposed to be conducive to the transfer, adaptation, and development of technologies consistent with the developmental goals of the country, Ethiopia has not yet achieved the anticipated socio-economic objectives or tapped the potential for technological development from the AEC industry (Woldesenbet, 2013, pp. 125-136).

To enhance and increase the performance and effectiveness of the construction sector, there are various systems and technologies which can be adopted, one of them being BIM. BIM is an innovative technology, workflow and data management system increasingly being used in the AEC industry worldwide that involves creating and managing digital models of buildings, infrastructure, and other physical assets throughout a building's lifecycle. Implementing BIM as a design process and construction quality control system will have significant advantages in achieving an efficient, integrated, and highly functional AEC industry (R. Zhang, 2011, pp. 219-243). The integration across the AEC sector as a whole will enable the sector to maintain integrity throughout any project's life cycle by providing the means to establish an efficient planning and control system. To take advantage of such kind of technology, it needs to be tested and evaluated to know its merits and shortcomings in our local context (John O. Adagba, 2020).

1.2 Problem statement

The BIM design process is regarded in such a way that it will greatly minimize design errors and reduce unforeseen complications in the construction phase. (Sengul, 2016) Most BIM models can be seen and verified via the computer, which enables them to accurately portray real life in an intelligent manner (Ergan, 2016). There is a lot of information available about BIM usage levels worldwide, particularly in developed nations (Gajendran, 2012). Despite many obstacles, the Architecture, Engineering, and Construction (AEC) industry as a whole has come to accept BIM because of its promising advantages worldwide.

Cost and time savings, quality and performance enhancements, clash detection, increased accuracy, improved collaboration and communication, better presentation and documentation process, improved planning and design, and better visualization are just a few of the ongoing BIM benefits experienced by industry practitioners (Diaz, 2016). BIM is generally seen as risk-averse, highly collaborative, and a better way of executing complex projects with fewer problems compared to the common way of designing (Rafael Sacks, 2018).

While BIM is being gradually incorporated into many construction projects in developed nations, this trend is not being seen in developing nations (Kassem, 2015). For instance, despite a slow uptake of BIM in the Middle East, a recent survey revealed that there are still only a small number of BIM users there (Mehran, 2016). The three main challenges were: resistance to change, comparisons between BIM and CAD, and the cost of BIM. The absence of government support, a lack of awareness, and the cost are some of the obstacles preventing BIM adoption (Alyami, 2019). As opposed to this, the enablers that promote the adoption of BIM include software, government support, training, and awareness (McGraw-Hill Construction, 2012).

Plans, elevations, sections, and other two-dimensional drawings are the way of Ethiopia's current design and construction system, with some 3D renderings being used for visualization and commercialization. Due to this, it has continued to use paper-based business practices, with limited standardization of design workflow, and inconsistent technology adoption among stakeholders (Taddese, 2016).

In Ethiopia, there is a growing recognition of the importance of Building Information Modeling (BIM) in large-scale government mega projects that exceed a budget of 1 billion Birr. However, a noticeable gap exists in studies that examine and evaluate the practical implementation of BIM within design firms or offices, specifically in real-world projects other than limited pilot projects or/and training scenarios. This research aims to address this gap by closely observing and evaluating the application of BIM workflow in an actual project, thus bridging the divide between theoretical knowledge and practical usage.

The study identifies two key issues that need to be addressed: the lack of comprehensive studies that move beyond theoretical frameworks and delve into the actual use of BIM in real-world scenarios, and to address the absence of contextually appropriate BIM workflows. To address these problems, a practical-based study is necessary to effectively evaluate the BIM workflow in action and develop appropriate frameworks and design workflows that align with specific contexts.

1.3 Research Questions

The research questions are mainly geared towards achieving the ultimate goal of the research which is to evaluate BIM as a design process and accessing the viability and validity in the local context for the AEC sector.

- What are the experiences of the BIM team and management at ECDSWC while implementing BIM on the CoESCoEM project?
- What are the challenges faced when transitioning from, the conventional design workflow to BIM workflow?
- What should the ECDSWC BIM workflow look like given the organization's structure and protocols?

1.4 General objective of the study

The main objective of this study is to develop a BIM workflow which is considerate of current conventional design workflow and protocol and which is easily integrated into other aspects the company without impacting productivity of parallel projects.

Specific objectives

- Examine the experiences of the BIM team and management at ECDSWC during the implementation of BIM on the CoESCoEM project.
- Identify the challenges faced by ECDSWC when transitioning from the conventional design workflow to the BIM workflow.
- Develop a contextually appropriate BIM workflow and technological framework for ECDSWC, considering the organization's structure and protocols.

1.5 Significance of the study

As BIM is becoming a critical tool to modernize the design process, it is important to evaluate and understand the real-world implications of implementing such a new design process, work environment, and collaboration platform in the architecture, engineering, and construction industry (British Standards Institution, 2020). The study aims to provide an objective assessment of the BIM application in the case of the CoESCoEM administration building. This can be achieved through collecting, analyzing, and correlating data from BIM users, BIM tool usage, and CoESCoEM design team members by employing an appropriate research methodology. In turn, the findings will help BIM stakeholders identify the current and future benefits that the CoESCoEM building management can achieve through implementing BIM in the design of their new headquarters.

With limited understanding, the BIM design process may seem like an obvious choice to execute most large-scale projects. But knowing the many challenges, requirements, and implications that a project may face in the real world while transitioning from the conventional method of design and construction to BIM is crucial to the success of any project. In turn, the findings will help BIM stakeholders identify the current and future benefits that CoESCoEM building management can achieve through implementing BIM in the design of their new headquarters.

1.6 Scope of the study

The spatial scope of the study will be undertaken in a specific location in Addis Ababa, Ethiopia, using a specific design phase project whereas the assessment will include the time, cost and quality of the design progress. In general, this study will narrate the development performance of the project using a BIM designing tool in the specific CoESCoEM project.

The thematical scope of this study focuses on the design process starting with forming a master plan for the compound's layout and then using BIM to design each building. Even though the center has many buildings, this study will only focus on the design phase and BIM implementation of the Administration building as well as justify the explanations through the design production of the project based on an iterative TCQ experiment.

1.7 Conceptual Frame work

The conceptual framework for this case study will provide a simplified and an overarching structure for the study, which identifies the key concepts, theories, and variables that will be explored. It also provides a roadmap for how the study will be conducted and analyzed, and what insights it is expected to generate (Yin, 2018).

- BIM: This is the central concept of the study, as it is the design workflow and technology being implemented. The conceptual framework should define BIM and provide a brief overview of its history, development, and potential benefits (Yin, 2018).
- Implementation: This concept refers to the process of introducing BIM into a construction project or organization. The conceptual framework should discuss the challenges and opportunities associated with BIM implementation, such as changes in work processes, training needs, and resistance to change (Yin, 2018).
- Organizational Culture: This concept refers to the values, beliefs, and behaviors that shape how people work together in an organization. The conceptual framework should discuss the role of organizational culture in BIM implementation, such as the importance of leadership support, collaboration, and communication (Yin, 2018).
- Innovation Diffusion: Exploring how new technologies are adopted and diffused within organizations. The conceptual framework should use this theory to explain how BIM implementation might progress through different stages, such as awareness, interest, evaluation, trial, adoption, and integration (Yin, 2018).
- Case Study: The case which the study is based on itself is a key component of the research. The data collected and the analytical approach will be important in developing the BIM implementation frameworks (Yin, 2018).

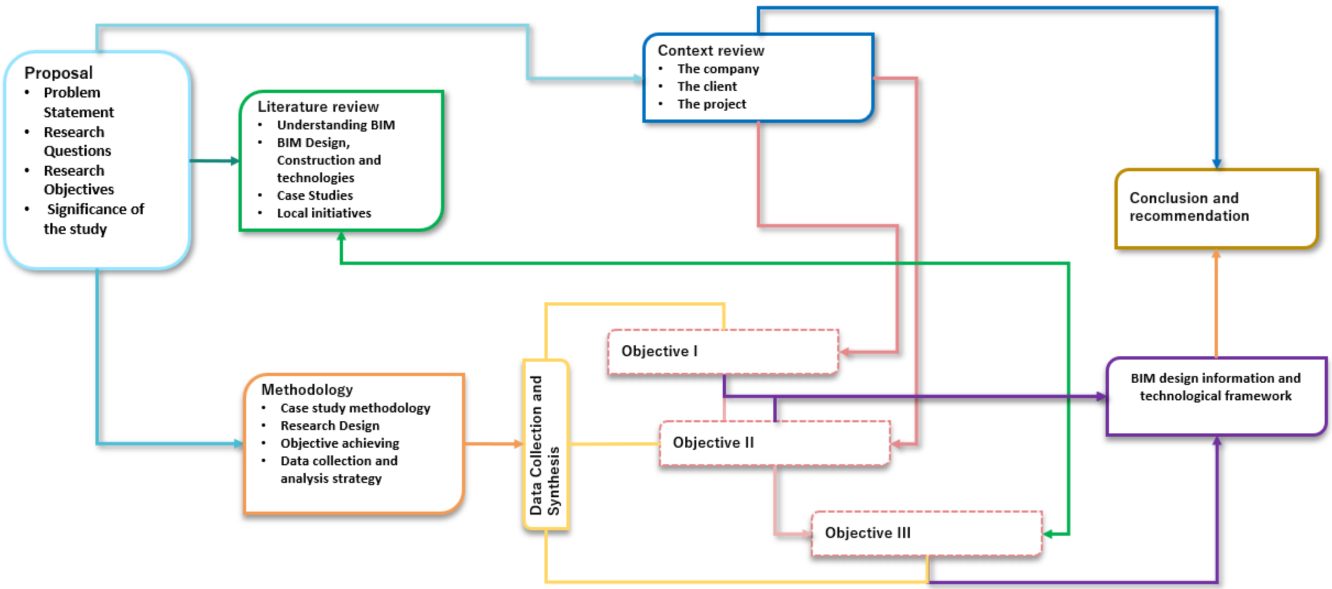

Figure 1 Conceptual Framework of the study

1.8 Limitations of the Study

The study's limitations revolve around its focus on the building design stage and its exclusion of the broader lifecycle of a project, the construction and maintenance phases. While the study aims to delve into the intricacies and challenges of the BIM design workflow, and technological framework it does not encompass the entire project lifecycle.

By solely concentrating on the design stage, the study may overlook important factors and interactions that occur during the construction and maintenance phases. These phases involve various stakeholders, such as contractors, subcontractors, facility managers, and maintenance personnel, who play crucial roles in the successful execution and operation of a project. One consequence of this limitation is that the study's findings and conclusions may need to fully account for the impact of construction and maintenance activities on the effectiveness or efficiency of the BIM design workflow.

Furthermore, the exclusion of the construction and maintenance phases limits the study's ability to provide a comprehensive understanding of the entire lifecycle of a project and the potential interdependencies and feedback loops between different stages. This holistic perspective is vital for identifying opportunities for improvement, optimizing processes, and enhancing collaboration across the entire project team. The study acknowledges these limitations and recognize the need for future studies that encompass the entire lifecycle workflow. Such studies would provide a more comprehensive understanding of the role of BIM in the context of the design, construction, and maintenance phases, enabling the development of a robust workflow throughout a project lifecycle.

Chapter 2 - Literature Review

2.1 Introduction

Building Information Modeling (BIM) has emerged as a transformative technology within the construction industry, revolutionizing the processes involved in project design, construction, and management (M. Reza Hosseini, 2022). In order to lay a strong foundation for the implementation of BIM, this chapter focuses on establishing a comprehensive theoretical understanding of its key aspects.

To begin with, an exploration of the historical background of BIM is crucial. By examining its origins and evolution since its inception, we can gain valuable insights into its current state and potential future developments. Furthermore, it is essential to delve into the benefits and challenges associated with the implementation of BIM across different industries, including architecture, engineering, and construction. In addition, this literature review examines the diverse definitions of BIM put forth by pioneers, researchers, industry professionals, and standards organizations. By analyzing these definitions, we aim to establish a shared understanding and conceptual framework that underpins the theoretical background of BIM.

To gain practical insights into BIM implementation, relevant case studies from various countries around the world are considered. By analyzing the experiences of different countries, valuable lessons can be learned and best practices identified to ensure successful implementation. This analysis also helps to identify any research gaps that exist in the field. Furthermore, this literature review critically evaluates the impact of BIM on conventional project delivery methods. By examining approaches such as Design-Bid-Build, Design-Build, and Integrated Project Delivery (IPD), we assess how BIM has influenced these methods within the architecture, engineering, and construction industry (McCool, 2015). Additionally, the legal and contractual implications of BIM adoption are thoroughly analyzed. This includes exploring challenges related to intellectual property rights, liability allocation, and the necessity for updated contractual frameworks. Understanding these legal considerations is vital for mitigating risks and ensuring the seamless integration of BIM into contractual agreements.

By synthesizing and analyzing existing literature in the areas mentioned above, this comprehensive literature review chapter aims to establish the theoretical backbone of BIM. It provides an in-depth overview of the key concepts and principles that underpin BIM, contributing to a better understanding of its implementation and potential impact on the construction industry.

2.2 The history of BIM

The concept of BIM has been in existence since the 1970s, the origin of the term "BIM" has been a subject of debate, with multiple claims regarding its first usage. One popular claim suggests that Charles M. Eastman, a prominent figure at Georgia Tech, coined the term. This belief stems from the notion that "building product model," a phrase extensively employed by Eastman in his publications since the late 1970s, is essentially synonymous with BIM (Guildhall, 1986).

However, it is important to note that the term "Building Information Modeling" as we currently understand it was officially introduced by G.A. van Nederveen and F. Tolman. In their December 1992 paper titled "Towards a Standard for the Exchange of Product Data in Building Construction". While the precise origins of the term "BIM" remain subject to discussion, the seminal work by van Nederveen and Tolman stands as a significant milestone in the development and popularization of Building Information Modeling, BIM.

Building Information Modeling (BIM) has its roots in the Computer-Aided Design (CAD) technology that emerged in the 1960s and 1970s. CAD enabled architects and engineers to create digital models of buildings and structures, which improved the speed and accuracy of design and drafting. However, CAD was limited to 2D drawings and lacked the ability to capture the rich and complex data that is involved in the building process (Eastman, 2011).

The first BIM tools for modeling buildings appeared in the 1990s. While there were earlier computer-aided design (CAD) systems that laid the groundwork for the digital representation of buildings. Reflex, ArchiCAD, MiniCAD, and Bentley Architecture were pioneering BIM software tools in the 1990s (Etiido, 2020). Reflex offered 3D modeling and digital representations of buildings, while ArchiCAD introduced parametric modeling, integrated drawing production, and object-oriented design. MiniCAD provided 2D drafting and 3D modeling, while Bentley Architecture laid the groundwork for later BIM tools like AECOsim Building Designer. Early applications, as well as the hardware required to run them, were prohibitively expensive, limiting their widespread adoption in the 1990s (Rafael Sacks, 2018).

In the mid-2000s, several countries, including the UK, the US, and Singapore, began to promote the adoption of BIM as a national standard for the AEC industry. This led to the development of industry standards and guidelines, such as the Building SMART Data Dictionary, the National BIM Standard-United States (NBIMS-US), and the Singapore BIM Guide. These standards helped to promote interoperability and consistency among different BIM software platforms, and encouraged the use of BIM across the industry (Eastman, 2011).

Today, BIM is widely recognized as a critical tool for the AEC industry, and is used by architects, engineers, contractors, and owners around the world. BIM has the potential to improve efficiency, productivity, and collaboration in the building process, and to enable better visualization and analysis of the building process (Gu, 2010). However, the adoption and implementation of BIM still face significant challenges, such as technological, organizational, and cultural barriers, and there is still a need for further research and development in this area (Challenges, 2016).

2.2.1 BIM Definitions

BIM, as we know it today, has evolved significantly over the past four decades and has now become a standard for documentation, construction, and even certain design and validation workflows in the public and commercial building industries (Eastman, 2011). To truly know what BIM is, we first need to define what it is. The following are some of the widely accepted definitions of BIM.

> Chuck Eastman: Charles M. Eastman, a prominent figure in BIM research, defines BIM as "the 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 lifecycle, from earliest conception to demolition." Eastman's definition highlights the comprehensive nature of BIM, encompassing both physical and functional aspects, and its role as knowledge resource throughout the entire lifecycle.

> G.A. van Nederveen and F. Tolman: In their groundbreaking 1992 paper, van Nederveen and Tolman define BIM as "a system of computer models that can be used for the design, construction, and management of buildings." Their definition emphasizes the utilization of computer models in various stages of the building process, encompassing design, construction, and ongoing management.

> National Institute of Building Sciences (NIBS): The NIBS defines BIM as "a digital representation of physical and functional characteristics of a facility." This concise

definition highlights the core concept of BIM as a digital representation while allowing for flexibility in its application across different types of facilities.

American Institute of Architects (AIA): AIA defines BIM as "a digital representation of the physical and functional characteristics of a facility, which serves as a shared knowledge resource for information about the facility." This definition aligns with the concept of BIM as a digital representation and emphasizes its role as a shared knowledge resource.

International Council for Research and Innovation in Building and Construction (CIB): CIB defines BIM as "a digital technology that facilitates the efficient creation, use, and exchange of information in the design, construction, and operation of a building or infrastructure asset." This definition underscores the efficiency benefits of BIM and its application across the entire lifecycle of a building or infrastructure asset.

Autodesk: Autodesk, a leading software provider for the AEC industry, defines BIM as "an intelligent model-based process that helps make design, engineering, project management, and construction of buildings more efficient, accurate, and cost-effective." This definition emphasizes the intelligent and process-oriented nature of BIM, with a focus on enhancing efficiency, accuracy, and cost-effectiveness.

There are a dozen other definitions in addition to the ones listed above. The abundance of BIM definitions reflects the rapidly expanding nature of the field. It also indicates the potential for misunderstanding to occur when vague language is used to illustrate particular concepts. BIM is a polysemous word. It can refer to both the digital representation of the physical and functional characteristics of a building (building information model) and the process of making the model and further harnessing its data (building information modeling) (Weisheng Lu, 2019).

What is BIM? It is critical to dispel the myths surrounding BIM, which is frequently promoted as the miracle cure for all problems in the construction sector. BIM is often promoted as the disruptive innovation that will revolutionize the AEC sector. Therefore, it is crucial to understand what BIM is and is not, given that it is credited with bringing about a paradigm shift in the global AEC industry (Ingram, 2020).

2.3 BIM as a design process

2.3.1 Level of Development

LoD is a measure of the information contained within a BIM model and the degree of accuracy it has compared to the reality it is representing. It serves as a "common language" for BIM users to understand the information in the model more specifically. LoD can stand for either "level of detail" or "level of development," which are sometimes used interchangeably in BIM applications despite their differing meanings (Rafael Sacks, 2018). Level of detail refers to the level of geometric and graphical detail contained in the BIM model, while the level of development refers to the completeness of the BIM model, including both graphical and non-graphical data. Throughout the project life cycle, the BIM model can be updated and its LoD increased as new information becomes available (ASC Technology Solutions LLC, 2022). This allows stakeholders to rely on the BIM model for more specific and accurate information, improving the overall efficiency and effectiveness of the project (Weisheng Lu, 2019).

In summary, LoD is a critical factor in BIM model development as it provides a measure of the information contained in the model and the degree to which stakeholders can rely on it. By updating the LoD as new information becomes available, BIM users can improve project efficiency and effectiveness (Build LACCD, 2009).

There are different levels of development in BIM, and they are typically organized into a standard hierarchy of increasing detail both graphically and non-graphically. Here is a breakdown of the typical LoD levels:

- **LoD 100**: Conceptual design - This level of development is used to convey the basic shape and form of the project. It contains minimal information and is typically used for feasibility studies and initial project planning (Rafael Sacks, 2018).

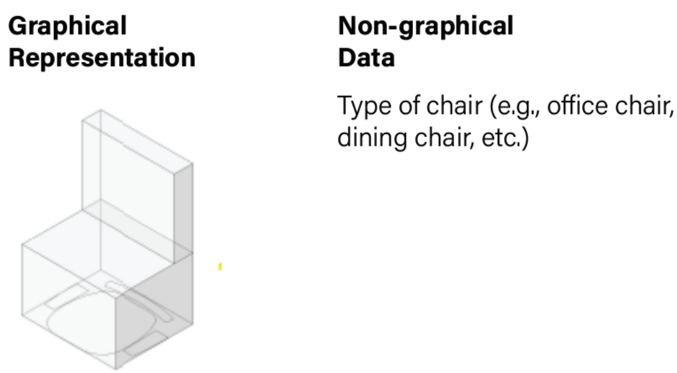

Figure 2 Example of a BIM objects at LOD 100

- **LoD 200:** Schematic design - This level of development provides more detailed information about the project's geometry, including the approximate size, shape, location, and orientation of the various components. It is used to create schematic design drawings and explore design options (Weisheng Lu, 2019).

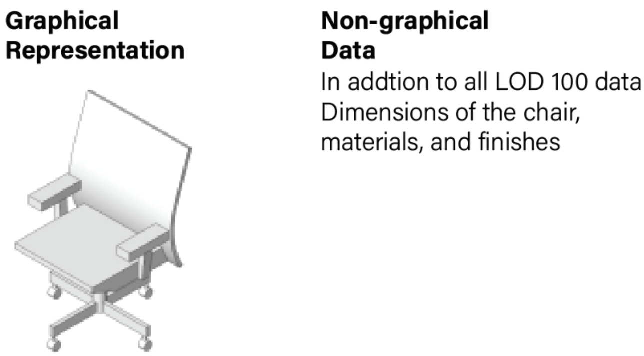

Figure 3 Example of a BIM objects at LOD 200

- **LoD 300:** Detailed design - This level of development includes detailed information about the project's geometry, such as precise dimensions, shapes, and locations of components. It may also include some non-graphical information, such as product specifications and quantities. This level of development is typically used for construction documentation and coordination (Weisheng Lu, 2019).

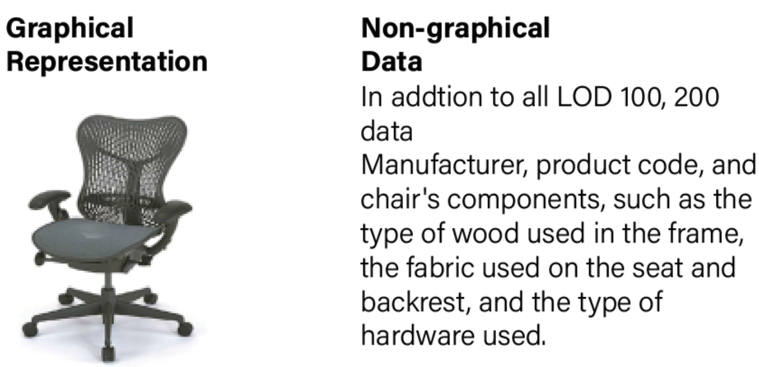

Figure 4 Example of a BIM objects at LOD 300

- ***LoD 350:** Is a slightly advanced stage of LoD 300 where the BIM model includes detailed information and collaboration across all driplines relative to LoD 300. While LoD 300 provides a moderate level of detail, LOD 350 offers a higher level of detail, coordination and accuracy in the BIM model.*

- **LoD 400:** Fabrication and assembly - This level of development includes specific information about how the components of the project will be fabricated and assembled, including connection details, materials, and other manufacturing information (Rafael Sacks, 2018).

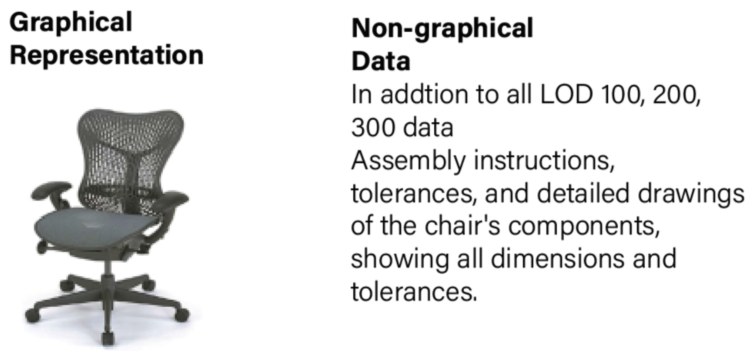

Figure 5 Example of a BIM objects at LOD 400

- **LoD 500:** As-built - This level of development includes all of the information necessary to create a complete as-built model of the project, including all of the graphical and non-graphical data. It is used for facility management and maintenance (Weisheng Lu, 2019).

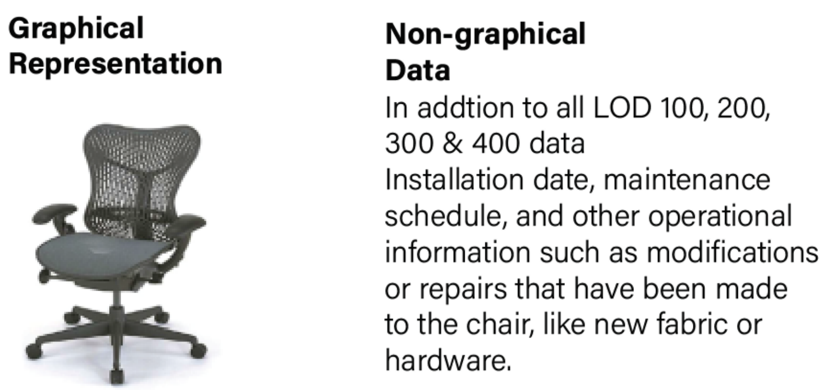

Figure 6 Example of a BIM object at LOD 500

2.3.2 BIM Levels

Levels of information technology maturity, the level of process cooperation, and the sophistication of tool use are all characteristics of BIM. According to this perspective, BIM represents a number of separate steps in a process that started with computer-aided drawing and is bringing the sector into the digital era. (Build LACCD, 2009) The UK Government BIM Task Group adopted the idea of "BIM Levels," according to which BIM is divided into four distinct phases. It defines the requirements for a project to be deemed BIM-compliant as Level 0 to Level 3, which has been extensively adopted worldwide. The levels and numbers refer to the British

Standards Institution, and the description of each level is their definition as well (British Standards Institution, 2020) (Niels Bartels, 2022).

BIM at Level 0. Unmanaged CAD is the definition of this category. This is probably in 2D, and the information is communicated through conventional paper drawings or, in some cases, digitally via PDF; these are basically different forms of information that cover the fundamentals of an asset. The vast bulk of the sector is currently far ahead of this (British Standards Institution, 2020).

BIM at Level 1 Many design and construction firms are presently functioning at this level. This usually combines 2D drafting for production information and regulatory clearance paperwork with 3D CAD for idea work. CAD standards are handled in accordance with BS 1192:2007, and computerized data exchange is done through a common data environment (CDE), which is frequently run by the contractor. Members of the project crew do not exchange models (British Standards Institution, 2020).

BIM at Level 2. Collaboration distinguishes this since each party uses their own 3D models and isn't working on a single, common model. The crucial element of this stage is the collaboration, which manifests itself in the information exchange between various partners. (Eastman, 2011) Any organization can merge that data with their own to create a federated BIM model and perform interrogative tests on it because design information is shared in a standard file format. Therefore, any CAD program that is used by each entity must be able to output to a standard file format like IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This is the method of working that has been set as a minimum target by the UK government for all work on public-sector work by 2016 (British Standards Institution, 2020).

BIM at Level 3. Through the use of a single, common project model that is stored in a centralized archive, this level symbolizes complete cooperation between all fields (normally an object database in cloud storage). This approach is accessible to all stakeholders, and one advantage is that it eliminates the last possible source of conflicting information. It is referred to as "Open BIM" (British Standards Institution, 2020).

BIM and IPD: Integrated Project Delivery (IPD) is a collaborative approach to project delivery that brings together all of the stakeholders in a project from the beginning. IPD is a collaborative approach to project delivery that brings together all of the stakeholders in a project from the beginning, leading to improved project outcomes, reduced errors, and enhanced efficiency in the architecture, engineering, and construction industry (ASC Technology Solutions LLC, 2022) (Ingram, 2020).

Figure 7 BIM maturity levels

2.3.1 BIM Technologies (tools and platforms)

BIM is a digital representation of a building that is to be built, is being built, or has already been built. The digital representation is materialized in BIM software packages and platforms are essential technological tools for the whole process. Many individuals incorrectly equate BIM with such software solutions or packages. An appropriate comparison would be to type a document in Microsoft Word. Word serves as the platform from which the document is viewed and created. The document and Word (i.e., the program) are not the same (i.e., the BIM) (Ingram, 2020).

BIM has become a common nomenclature to refer to a family of technologies and related practices used to represent and manage the information used in and created by the processes of designing, constructing, and operating buildings. (Build LACCD, 2009)The best way to comprehend and use BIM tools is to evaluate each option objectively, free from the commercial considerations that direct the development of BIM software, and to ascertain what the building information modeling process actually requires of the BIM platforms and tools (British Standards Institution, 2020).

All digital files are produced by using CAD systems. These CAD platforms produce files that are primarily made up of different line types and layer names for each vector element. As these systems evolved, more data was added to enable the embedding of data blocks and their corresponding text within each vector element. Texturing tools were added along with 3D modeling, advanced geometry definition, and complex surfacing. The emphasis shifted from drawings and 3D images to the data itself as CAD systems became more intelligent and users expressed a desire to share data related to a particular design. A BIM tool's generated building model can accommodate both 2D and 3D views of the information present in a drawing set (M. Reza Hosseini, 2022).

According to the Illinois Institute of Technology, there are more than 30 BIM programs, and each serves different purposes. Models produced using BIM enabled tools and platforms have characteristics as follows (Rafael Sacks, 2018).

- Building components that are represented by digital models (objects) that have parametric rules that enable intelligent manipulation and computable graphic and data attributes that identify them to BIM enabled tools and platforms.
- Components with behavior data necessary for analyses and work processes like amount takeoff, specification, and energy analysis.
- Consistent and nonredundant data that allows for the representation of data changes in all views of the component and the components of which it is a part.

The following are some of the most common and widely used BIM platforms and tools and their capabilities. These platforms and tools are essential for architects, engineers, and construction professionals to effectively collaborate and manage building projects.

Autodesk AEC collection: Autodesk is widely known BIM software provider and is the current market leader in architectural, structural, mechanical, electrical, and plumbing (MEP) design. It was originally developed by a start-up company and was later acquired by Autodesk in 2002. Multiple specialized versions were released over the coming years to enable BIM use in specific disciplines. Autodesk Revit was then rolled into one product in 2013, an integrated BIM platform that facilitates collaboration amongst different stakeholders. Revit supports the creation of predefined and parametric BIM objects and provides embedded rules to ensure the models form realistically. It also provides bidirectional associativity between drawings, models, components, views, annotations, and schedules. Navisworks is project review software that facilitates a comprehensive appraisal of aggregated models and data (National BIM Standard (NBIMS) and the National Institute of Building Sciences (NIBS), 2007).

ArchiCAD: ArchiCAD is a BIM system developed by Graphisoft in the 1980s and acquired by a German CAD organization in 2007 (Etiido, 2020). It features smart cursors, context-sensitive operator menus, and drag-over operation hints, allowing users to merge drawing details, different model sections, and 3D images into different layouts. It incorporates a large collection of predefined parametric objects, including modeling capabilities for site and space planning. The built-in object libraries provide extensive resources, such as metals, precast concrete, wood, masonry, thermal and moisture protection, heating, ventilation, and air conditioning (HVAC), plumbing, and electrical. Users can apply the system to almost all phases of a project except fabrication. In addition, the memory inside the system is not always sufficient to handle large projects (National BIM Standard (NBIMS) and the National Institute of Building Sciences (NIBS), 2007).

Dassault Systems and CATIA: Dassault Systems (DS) is a multinational software company that develops 3D design, 3D digital mock-ups, and product lifecycle management (PLM) software. Its BIM roots trace back to the production and manufacturing industries, but its history dates back to a group of engineers specializing in aircraft design. CATIA was the PLM solution for 3D collaborative creation, and DELMIA allows manufacturers to virtually define, plan, create, monitor, and control all production processes. ENOVIA provides a framework for collaborative management; SIMULIA is for virtual testing and simulation; and DS is designed to meet companies' needs for realistic product and process simulation software and to make lifelike project mock-ups more readily accessible (National BIM Standard (NBIMS) and the National Institute of Building Sciences (NIBS), 2007).

Tekla: Tekla software provides a variety of tools, including Tekla Structures, Tekla Structural Designer, and Tekla Tedds, for design and detailing, project team review, and communication (Tekla, 2023). Tekla BIMsight is a piece of software for BIM-based construction project collaboration that enables users to coordinate space and interact with others. Tekla Structural Designer is a piece of software that structural engineers prefer because it was created for building structural design and analysis (Build LACCD, 2009).

Bentley Systems: Bentley Systems provides a suite of functions for architecture, engineering, infrastructure, and construction, including predefined parametric objects, strong modeling capabilities, solid drawing capabilities, drag-over operation hints, a smart cursor, and user definable menu setups (Bentley Systems, 2023). Bentley is primarily suited for civil engineering projects (Build LACCD, 2009).

Glodon: Glodon Software is a China-based software company focused on BIM software development relating to the life cycle of a construction project. It recently rebranded its flagship BIM solution as Cubicost, which aims to provide the construction industry with a more precise and expedient BIM-integrated solution through its four major products: TAS, TRB, TME, and TBQ (Bernard, 2003). China has a relatively short history of using BQ, but the standard has its own peculiarities. Glodon is also developing rapidly, with revenue of 1.8 billion yuan in 2014 and net profit of 596 million yuan. It has established an international presence and focuses on niche markets to develop its BIM businesses (Gajendran, 2012).

There are numerous additional BIM platforms and tools available that support the process at various stages and aid the various professionals involved. Interoperability is the key to any BIM tool for fostering file sharing across various families of software; any BIM software at least needs to be able to export and import files or data using the common IFC (Industry Foundation Classes) or other equivalent formal (Royal Academy of Engineering , 2016).

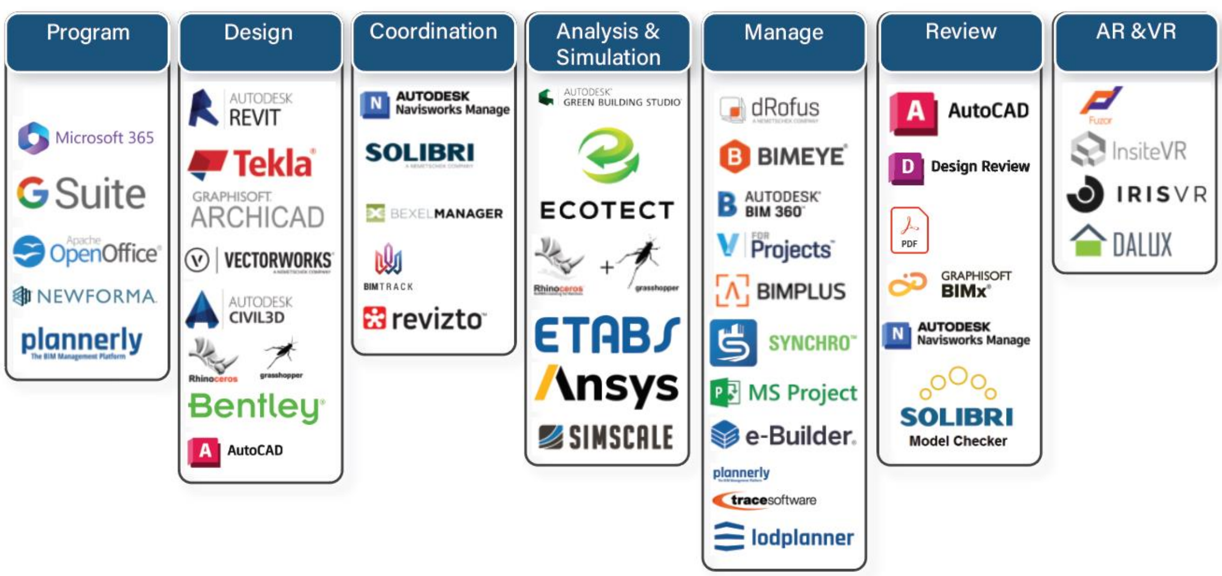

Figure 8 Some BIM tools and platforms in their relevant category

2.3.2 BIM Workflow

Unlike methods of production in other industries, which favored the linear and rote repetition of tasks by an assembly line of individuals, these BIM enabled improvement flows can be discontinuous or circular. The BIM workflow will allow the design to become technologically and technically rationalized to be both novel and efficient. This means that BIM can break away from conventional production methods and allow for more creative and innovative designs iterations (Francois Levy, 2019, pp. 9-12).

All parties involved in a holistic BIM workflow, including design firms, construction companies, owners, and regulators, collaborate to improve communication, coordination, and efficiency. It consists of three core components: technology infrastructure, organizational infrastructure, and contractual, regulatory, and preparatory aspects (Rafael Sacks, 2018). A solid technology infrastructure allows for seamless data sharing, reducing errors. Organizational infrastructure ensures team members are trained to use BIM tools, fostering collaboration and innovation contractual & regulatory aspects to ensure legal and regulatory requirements are met.

1. **Technology Infrastructure:**

   Software: BIM relies on specialized software tools that enable the creation, management, and sharing of digital building models. These software applications facilitate collaboration and data integration (Succar, 2009).

   Hardware: The hardware infrastructure includes computers, workstations, servers, and mobile devices necessary for running BIM software effectively (Succar, 2009)..

   Network: A robust network infrastructure is crucial for seamless data exchange and collaboration among project participants. It ensures that stakeholders can access and work on BIM data from various locations (Succar, 2009).

2. **Organizational Infrastructure:**

   Leadership: Effective leadership and project management are essential for implementing and sustaining a BIM workflow. Clear direction, vision, and commitment from leadership help drive the adoption of BIM throughout the organization (Succar, 2009)..

   Human Resources: Skilled professionals, including architects, engineers, and project managers, are critical for the successful execution of a BIM workflow. Continuous training and development ensure that team members can effectively use BIM tools (Succar, 2009).

Products & Services: Access to appropriate BIM-related products and services, including templates, libraries, and third-party support, enhances the workflow's efficiency and effectiveness (Succar, 2009).

3. **Contractual, Regulatory, and Preparatory Aspects:**

   Contractual Agreements: BIM workflows often require specific contractual arrangements among project stakeholders to define roles, responsibilities, and data-sharing protocols. These agreements set the foundation for collaborative work (Succar, 2009).

   Regulatory Compliance: Ensuring that the BIM workflow aligns with local building codes, standards, and regulations is crucial. Compliance helps maintain project integrity and safety (Succar, 2009).

   Preparatory Work: Adequate preparation includes data collection, model standards, and establishing clear project goals. This phase lays the groundwork for a successful BIM workflow implementation (Succar, 2009).

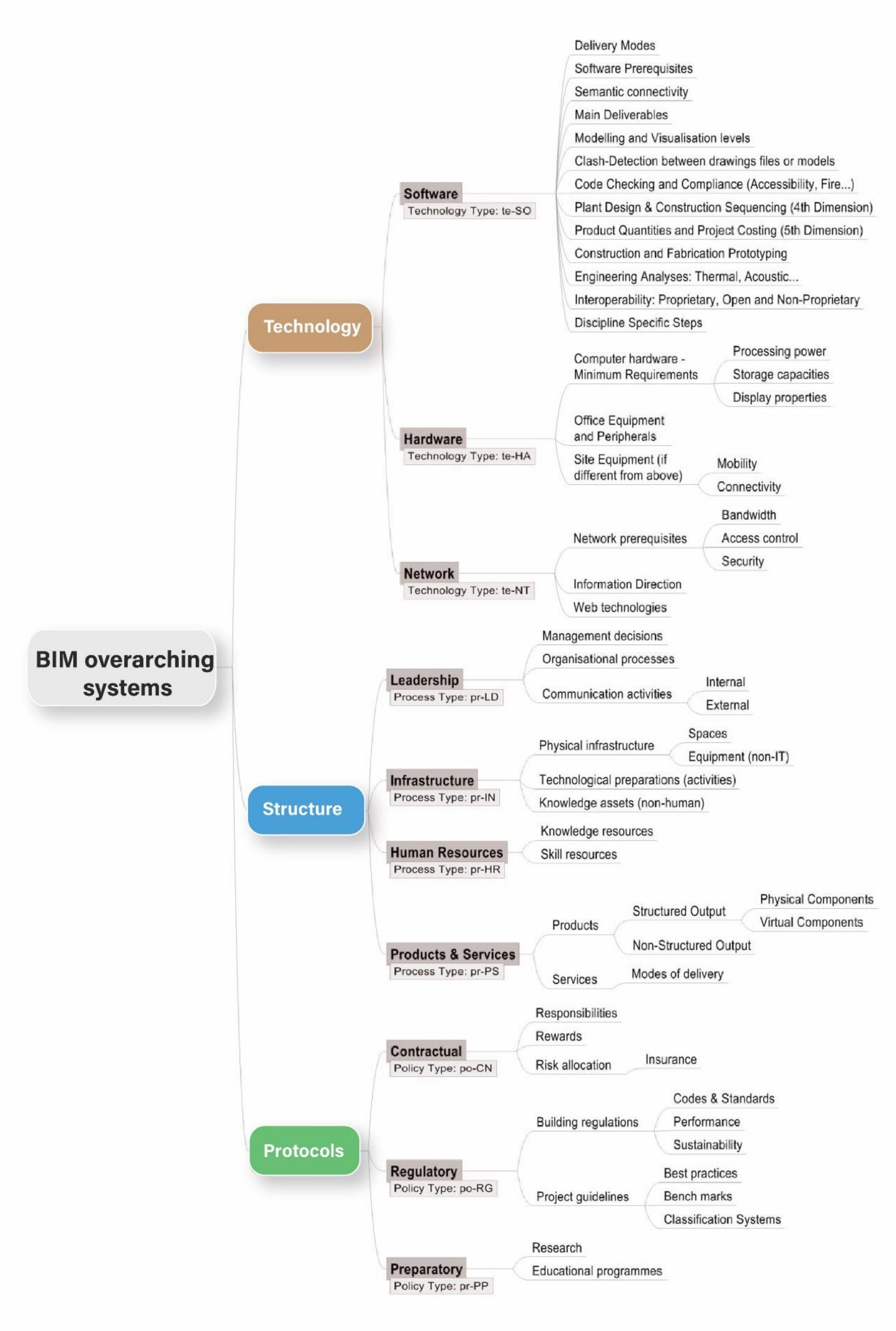

Figure 9 The BIM workflow based on (Succar, 2009).

An integrated Building Information Modeling (BIM) model is a central data repository that integrates data from various disciplines, such as architecture, engineering, and construction, allowing teams to work collaboratively within a shared environment (M. Reza Hosseini, 2022). It centralizes project-related data, including 2D and 3D models, specifications, schedules, cost estimates, and documentation, promoting data consistency (M. Reza Hosseini, 2022). The model is continuously updated as project information changes, reducing errors and conflicts. It supports interoperability, allowing different software applications and file formats to exchange data seamlessly, promoting collaboration among different disciplines. BIM models also offer clash detection capabilities, enabling early detection and resolution of issues. They provide 3D visualization, enabling stakeholders to see the project in a realistic context, aiding design evaluation, communication, and understanding (M. Reza Hosseini, 2022). They also enable accurate cost estimation and analysis throughout the project's life cycle, supporting budgeting and financial decision-making. BIM models can extend beyond the construction phase to support facility management, facilitating long-term operations and maintenance. They serve as a central platform for communication and collaboration among all project participants, including architects, engineers, contractors, owners, and regulators (Eastman, 2011). They can also be used for data analytics and

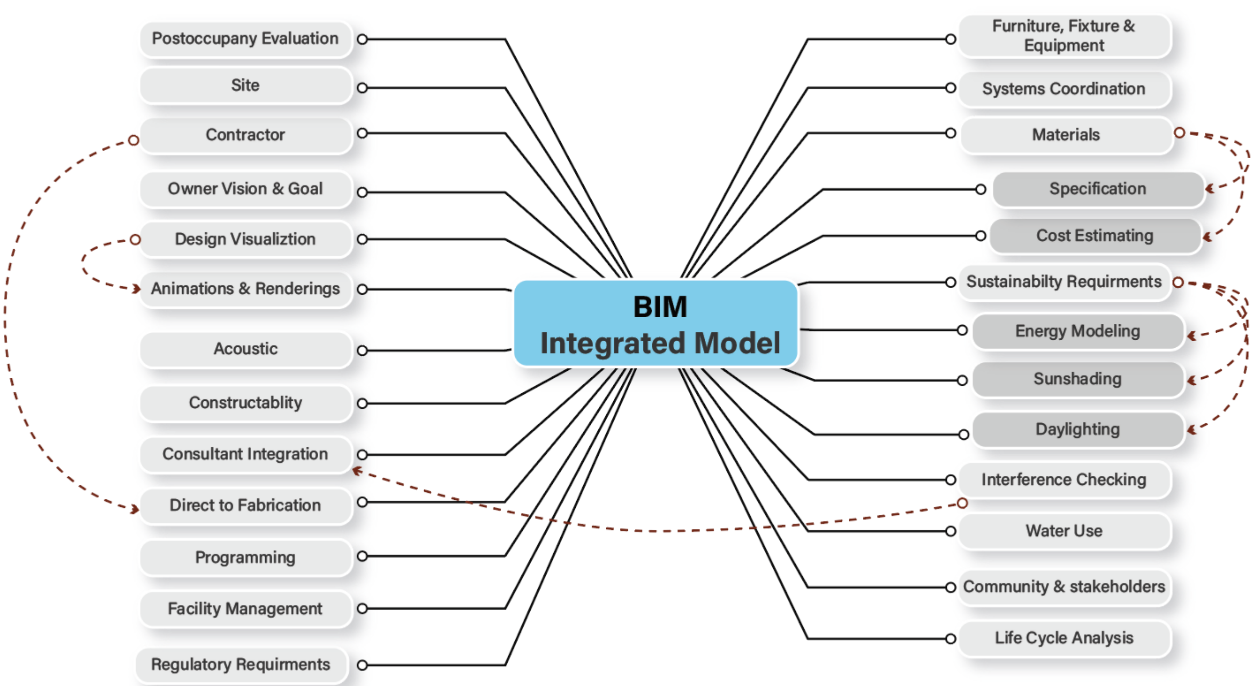

Figure 10 An Integrated Building Information Model based on (Silverio, 2021)

sustainability analysis.

2.4 BIM ISO standards

BIM ISO standards are a set of international standards developed by the International Organization for Standardization (ISO) that provide guidelines for the implementation of BIM in construction projects. These standards cover various aspects of BIM implementation, including data exchange, information management, and collaboration between project stakeholders. Adherence to these standards can improve project efficiency, reduce errors and conflicts, and enhance overall project outcomes (International Organization for Standardization, 2023).

There are several BIM ISO standards developed as a series related to BIM, which are intended to help organizations adopt and implement BIM more effectively. Here are some of the key ISO standards related to BIM: (International Organization for Standardization, 2023).

- ISO 19650-4:2022 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 4: Information exchange
- ISO 19650-3:2020 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information management using building information modelling -- Part 3: Operational phase of assets. This standard provides guidance for managing information during the operational phase of a building or civil engineering project, using BIM. It covers topics such as asset management, maintenance, and facility management.
- ISO 19650-5:2020 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information management using building information modelling: Use of building information models in procurement.

- ISO 19650-1:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information management using building information modelling. This standard provides guidelines for managing information throughout the entire lifecycle of a building or civil engineering project, using BIM. It covers topics such as information requirements, information exchanges, and the use of common data environments (CDEs).
- ISO 19650-2:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information

management using building information modelling -- Part 2: Delivery phase of the assets. This standard provides guidance for managing information during the delivery phase of a building or civil engineering project, using BIM. It covers topics such as information delivery plans, model coordination, and information handover.

- ISO 29481-1:2016 - Building information models -- Information delivery manual -- Part 1: Methodology and format. This standard provides guidelines for creating and using information delivery manuals (IDMs) in BIM projects. IDMs are used to define the information requirements for a project and to ensure that the information is delivered in a consistent and structured manner.
- ISO 16739:2013 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. This standard defines a data schema for BIM data, known as Industry Foundation Classes (IFC). IFC is an open, neutral, and internationally recognized standard for exchanging information between different BIM software tools and applications.

As of writing April 2023 there are a number of other standards that are still under development which are expected to be released in the near future.

- ISO/CD 19650-6:2023 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 6: Health and Safety.
- ISO/CD 19650-7:2023 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -- Information management using building information modelling: Sustainability information.

These ISO standards are designed to help organizations adopt and implement BIM more effectively, by providing guidance on information management, data exchange, and interoperability between different software tools and applications and can be purchased from the publisher directly in a digital format.

2.6 Implementation of BIM in other countries (case studies)

2.6.1 African Experience

The case study on Building Information Modeling (BIM) adoption in various African countries, including Egypt, Nigeria, South Africa, and Kenya, offers valuable insights into the challenges and opportunities associated with the implementation of this technology in the construction industry across the continent. This review critically assesses the findings and recommendations presented in the case study while adding new perspectives and analysis.

The studies show that BIM adoption in Egypt is still at its nascent stage, with limited awareness and understanding among industry stakeholders (Elyamany, 2016), (Marzouk, 2021). This observation aligns with (Elyamany, 2016) prior findings (Khodeir, 2017). While the studies identify challenges such as government support, technical infrastructure, skilled labor shortages, and resistance to change, it also important to emphasizes the growing interest and investments in BIM (Marzouk, 2021). To further this analysis, it's essential to recognize that overcoming these challenges requires a comprehensive approach involving not just government support but also industry-wide collaboration to foster knowledge sharing and skill development. (Marzouk, 2021)

In Nigeria, study corroborates the notion that BIM adoption is in its early phases (Ruya Tambaya Fadason, 2018). The primary challenges cited, including a lack of education and information, along with insufficient investment, underscore the need for improved awareness and financial backing in the Nigerian context (Ruya Tambaya Fadason, 2018). In addition to their recommendation that educational institutions incorporate BIM into curricula, it's essential to stress the importance of private sector engagement in addressing these issues. Companies can play a pivotal role in investing in training and skill development for their workforce (Ruya Tambaya Fadason, 2018).

The South African case reveals that BIM adoption initially gained momentum during the 2010 FIFA World Cup, but clients' indifference to BIM persists due to the dearth of BIM-related studies (Harris, 2016). This points to a significant research gap in South Africa. To further this discussion, one can argue that conducting more research and disseminating its findings can stimulate interest and awareness among clients. Additionally, the study emphasizes that the perceived benefits of BIM, such as improved communication and productivity, can drive its adoption (Harris, 2016). This suggests that showcasing these advantages through case studies and success stories could enhance BIM's uptake in South Africa.

In Kenya, study emphasizes the importance of government involvement in BIM adoption among building contractors (Dr. Githae Wanyona, 2015). The positive correlation found between government involvement and BIM adoption highlights a key lever for advancing BIM in the country. To build on this, it's essential to stress that government intervention should encompass not only regulations and policies but also direct support in the form of training programs and incentives (Oyuga, 2021). This multi-pronged approach can effectively address the barriers of awareness and skills while fostering a conducive environment for BIM implementation (Oyuga, 2021).

In conclusion, the case studies provide a comprehensive overview of the BIM landscape in various African countries, shedding light on the challenges and opportunities unique to each region (Ogwueleka, 2017). To facilitate the adoption of BIM across the continent, it is crucial for governments, educational institutions, and private sector stakeholders to collaborate and address the identified barriers while leveraging the potential benefits of BIM for improved construction outcomes, reduced costs, and enhanced communication among stakeholders (Diaz, 2016). Further research and knowledge sharing will be instrumental in driving BIM adoption in African countries.

2.6.2 Asian Experience

The case studies presented provide valuable insights into the adoption and implementation of Building Information Modeling (BIM) in the construction industries of Pakistan, China, Malaysia, and India. Each of these studies identifies unique challenges and opportunities, shedding light on the diverse landscape of BIM adoption across different Asian countries.

In Pakistan, (Farooq, 2020) employed Interpretive Structural Modeling (ISM) to pinpoint key barriers and issues in BIM implementation. The classification of these challenges into technological, organizational, legal, and social categories highlights the multifaceted nature of the problem. The study's identification of limited BIM expertise and data interoperability issues as significant barriers underscores the need for comprehensive training programs and standardized data practices (Farooq, 2020). This aligns with the authors' recommendation for collaboration among policymakers, professionals, and academia to develop a robust BIM framework for Pakistan's construction industry (R. Masood a, 2014).

In China, (Tan, 2019) emphasizes the importance of standardization in BIM implementation, ranking it as the most critical barrier. The call for government intervention in developing industry standards and regulations is well-founded, as it can provide a solid foundation for BIM adoption. Furthermore, the study's focus on human resources and collaboration among stakeholders suggests that a holistic approach to skill development and partnership-building is essential for successful BIM integration in China's prefabricated construction sector (Tan, 2019).

In Malaysia, (Haron, 2017) take a comprehensive approach by reviewing previous studies on BIM implementation. They recognize the government's role in promoting BIM and advocate for the development of standards and guidelines, a crucial step towards widespread adoption. The highlights are the need for improved education and training programs, especially for small and medium-sized enterprises (SMEs) (Haron, 2017). The acknowledgment of BIM's potential to enhance project coordination and visualization, as well as reduce errors and rework, underscores the long-term benefits of its implementation.

In India, the recognition of BIM's potential for improving efficiency and collaboration resonates with global trends in the industry (Nanajkar, 2014). However, the study underscores the challenges of a skills gap, high software costs, and resistance to change. Their recommendation for both AEC firms and the government to address these issues aligns with the broader goal of ensuring India's competitiveness in the global construction market (Nanajkar, 2014).

In conclusion, these case studies collectively emphasize the need for coordinated efforts from various stakeholders, including governments, professionals, and academia, to overcome the barriers to BIM adoption in Asian countries. The significance of standardization, education, and government support resonates across these studies, highlighting their critical roles in shaping the future of BIM implementation in the region. These insights offer valuable guidance for policymakers and industry leaders as they work towards harnessing the potential of BIM to revolutionize the construction industry in Asia.

2.6.3 European Experience

The case studies on Building Information Modeling (BIM) adoption in various European countries provide valuable insights into the strategies and challenges associated with implementing this digital approach to construction. These studies shed light on the different approaches taken by countries with distinct industry landscapes and governmental support. This critical review will analyze and extract insights from each case study while drawing connections and distinctions between them.

In the United Kingdom, (Ghaffarianhoseini, 2016) outline a practical strategy for Small and Medium Enterprises (SMEs) to adopt BIM, emphasizing the importance of readiness assessment, implementation planning, and BIM execution. Their approach highlights the significance of evaluating a company's current BIM knowledge and addressing barriers to adoption (Ghaffarianhoseini, 2016) . The UK's proactive stance in promoting BIM is evident through such strategies, enabling SMEs to stay competitive (Ghaffarianhoseini, 2016).

Contrastingly, Italy, as discussed by (Karampour, 2021), faces challenges like limited government support and resistance to change. However, the use of the Diffusion of Innovation (DOI) theory provides a structured plan for overcoming these barriers (Karampour, 2021). Identifying early adopters, providing training, and fostering collaboration are essential components of Italy's BIM diffusion strategy (Karampour, 2021). The DOI theory-based approach serves as a valuable blueprint for countries grappling with slow BIM adoption.

In Germany, (Borrmann, 2021) delve into the BIM4INFRA2020 project, a governmental initiative aimed at advancing BIM adoption in infrastructure projects. The project's strategic plan, including the development of standards, guidelines, and training programs, showcases Germany's commitment to establishing BIM as an integral part of its infrastructure projects (Borrmann, 2021). This project serves as a model for comprehensive BIM implementation in large-scale projects.

In France, as explored by (Lahiani, 2020), has been comparatively slow in adopting BIM within its construction industry. Nonetheless, the benefits highlighted in are, such as improved collaboration, accuracy, and sustainability, underscore the potential gains from BIM implementation (Sebastiano Maltesea, 2016). However, it is important to emphasizes the necessity of a cultural shift, training, and government support to facilitate BIM adoption in France.

In Europe, the case studies across the UK, Italy, Germany, and France reveal the multifaceted nature of BIM adoption in the European context. While each country faces unique challenges, there is a common thread of recognizing the transformative potential of BIM in enhancing construction processes, collaboration, and project outcomes. The strategies discussed in these case studies, whether through readiness assessment, DOI theory, governmental initiatives, or cultural shifts, offer valuable lessons for other nations aiming to embrace BIM as a fundamental part of their construction industry. The diversity of approaches also underscores the importance of tailoring BIM adoption strategies to the specific context and challenges faced by each country or organization.

2.6.4 Middle Eastern experience

The case studies presented here shed light on the status of Building Information Modeling (BIM) adoption in various Middle Eastern countries, including the United Arab Emirates (UAE), Kingdom of Saudi Arabia (KSA), and Qatar. Each study offers valuable insights into the challenges and opportunities surrounding BIM implementation in the construction industry in these nations.

In the UAE, BIM is growing in importance, driven by government mandates and recommendations to address inefficiencies in the construction sector (Mehran, 2016). The critical factors influencing BIM adoption, including technology-related issues such as interoperability and software compatibility, organizational factors like professional training and senior management support, and attitude-related factors encompassing awareness and willingness to embrace BIM (Mehran, 2016). A notable finding is the lack of a unified BIM definition and industry-wide standards, which contribute to confusion and hinder adoption (Mehran, 2016).

To advance BIM adoption in the UAE, it is suggested in investing in training and education, developing BIM standards, and fostering a culture of innovation and collaboration within organizations (Mehran, 2016). Moreover, the role of government support in promoting BIM in the UAE construction industry is pivotal.

(Alyami, 2019) study on BIM adoption in Saudi Arabia also underscores the benefits and barriers of BIM. While BIM adoption is increasing, it remains in its nascent stages (Alyami, 2019). Benefits include improved project quality, reduced project duration, and enhanced collaboration. Barriers encompass a lack of awareness, inadequate technical infrastructure, and resistance to change. (Austyn, 2014) There is an emphasizes the need for overcoming these barriers to fully leverage the potential advantages of BIM.

In a similar vein, (Elhendawi, 2018) research in KSA proposes a comprehensive methodology for BIM implementation, consisting of six stages: awareness and education, readiness assessment, implementation planning, execution, monitoring and control, and maintenance and continuous improvement (Elhendawi, 2018). This structured approach aims to bridge gaps in skills, processes, and technology and highlights the importance of government support and incentives to facilitate BIM adoption in KSA's AEC industry.

Moving to Qatar, (Mohammed, 2019) study discusses the challenges and opportunities associated with BIM implementation. Their findings underline the potential efficiency and productivity enhancements offered by BIM but also emphasize the need for standardization and increased training for BIM professionals (Mohammed, 2019). They advocate for greater collaboration and communication among stakeholders and the establishment of BIM standards and guidelines to facilitate more consistent and effective implementation.

In conclusion, these case studies collectively demonstrate that BIM adoption in the Middle East is on the rise, albeit with notable challenges (Austyn, 2014). Common themes include the importance of government support, education and training, and the need for standardized practices. Addressing these factors will be crucial for the successful integration of BIM in the construction industries of the UAE, KSA, and Qatar, ultimately leading to more efficient and innovative projects in the region.

2.6.5 North American experience

In examining the North American experience with Building Information Modeling (BIM), it is evident that the United States and Canada have both made significant strides in adopting and implementing this innovative digital tool in the construction industry. While the case studies discussed by (Gajendran, 2012) focus on the U.S. and, (Moazzami, 2020) provide insights into the Canadian context. These two perspectives offer a valuable opportunity to explore the commonalities and distinctions in the adoption and impact of BIM in North America.

In the United States, the General Services Administration (GSA) is recognized as a pioneering organization in implementing BIM within the government (Gajendran, 2012). The GSA's launch of the national 3D-4D BIM initiative in 2003 marked a significant milestone in promoting BIM-enabled construction methods. The case studies presented by Gajendran et al. (2012) highlight how BIM has been utilized in various projects, such as the tsunami warning center and hospital expansion plan. These case studies illustrate how BIM facilitates sustainable design, enhances teamwork, reduces redesign needs, and ultimately leads to cost savings and earlier project completion.

Furthermore, the survey conducted by the authors (Gajendran, 2012) underscores the industry's perception of BIM's utility. Visualization, collision detection, and building design emerge as the primary applications of BIM, aligning with its core capabilities. The findings reveal a correlation between experience and profitability, with more experienced users deriving greater benefits from BIM adoption. Additionally, the preference for Revit products among users emphasizes the importance of selecting the right BIM adoption package to optimize cost efficiency and project duration (Gajendran, 2012).

In contrast, the Canadian perspective presented by (Moazzami, 2020) sheds light on the benefits, challenges, and limitations of BIM adoption in Canada. The benefits, including improved collaboration, enhanced project visualization, efficiency gains, cost reduction, and error minimization, resonate with the U.S. experience. However, it is crucial to acknowledge the challenges faced in Canada, such as the high cost of BIM software and hardware, the absence of standardized processes, and limited expertise among stakeholders (Moazzami, 2020).

Both case studies emphasize the significance of overcoming cultural and organizational barriers to foster BIM adoption effectively. Moreover, the common limitations of BIM, such as the need for substantial initial investment, standardized data exchange protocols, and concerns about data privacy and security, underscore the importance of addressing these issues to fully harness the potential benefits of BIM.

In conclusion, the North American experience with BIM reveals a shared recognition of its potential to revolutionize the construction industry. While the U.S. has made considerable progress through government initiatives and successful case studies, Canada faces similar opportunities and challenges. The key takeaway from these studies is the need for a strategic and collaborative approach to BIM adoption, one that addresses both its promises and pitfalls. By doing so, North American construction projects can unlock the true potential of BIM to enhance efficiency, reduce costs, and improve project outcomes.

2.6.6 South American Experience

The case studies conducted by (Silverio, 2021) in the Dominican Republic and (Arrotéia, 2021) in Brazil shed light on the current state of Building Information Modeling (BIM) adoption in South America, offering valuable insights into the challenges and opportunities within these distinct contexts.

In the Dominican Republic, BIM implementation is still at an early stage, with construction professionals demonstrating a low level of awareness and understanding of the concept (Silverio, 2021). This finding underscores the need for educational initiatives and training programs tailored to the Dominican Republic's construction industry. The study also identifies key drivers for BIM adoption, including improved collaboration, communication, efficiency gains, and cost reduction. However, the lack of government support and the high cost of BIM software are significant barriers inhibiting its widespread use. To foster BIM's growth in the Dominican Republic, policy development and regulatory support are essential to address these issues and facilitate its integration into construction projects (Silverio, 2021).

In the Brazilian context, the economic and organizational factors are the most substantial impediments (Arrotéia, 2021). High software and hardware costs, coupled with inadequate return on investment, deter construction firms from embracing BIM. Organizational challenges, such as resistance to change and a lack of collaboration, also hinder implementation. Legal and contractual barriers, such as the absence of BIM standards and protocols, create uncertainty and hamper progress. Cultural and educational issues further compound the problem, as awareness and expertise in BIM remain limited (Arrotéia, 2021).

To overcome these barriers in Brazil, the study suggests multifaceted strategies. Developing BIM standards, protocols, and guidelines can provide a much-needed framework, while improving education and training programs can enhance professionals' BIM proficiency (Arrotéia, 2021). Encouraging collaboration among stakeholders and promoting a supportive regulatory environment are also crucial steps. Government agencies and industry associations must play a pivotal role in facilitating BIM's acceptance by providing incentives and creating an ecosystem that fosters its use.

In both cases, the studies emphasize the importance of comprehensive approaches to overcome the challenges and promote BIM adoption. The Dominican Republic and Brazil can learn from each other's experiences and adapt best practices to accelerate the integration of BIM into their respective construction industries. These findings are not only applicable to these countries but can also serve as valuable insights for other South American nations striving to harness the benefits of BIM technology in construction.

2.6.7 Australian Experience

Research conducted by Hosseini, M. Reza & Banihashemi, Saeed & Chileshe, Nicholas & Oraee, Mehran & Udeaja, Chika & Rameezdeen, Raufdeen & McCuen, Tamera. (2016) examines the factors that affect the adoption of Building Information Modeling (BIM) technology among Small and Medium-sized Enterprises (SMEs) in Australia. The authors used an innovation diffusion model to analyze the factors affecting BIM adoption, including the perceived characteristics of BIM, innovation attributes, external factors, and organizational factors.

The study used a mixed-methods approach, involving a survey of 155 SMEs in the Australian construction industry and in-depth interviews with 12 industry experts. The findings revealed that the perceived compatibility of BIM with existing processes and systems, its relative advantage over existing technologies, and its complexity are significant determinants of BIM adoption. Other factors that influence adoption include organizational culture, leadership support, and external pressure from clients and regulatory bodies (Hosseini, 2016).

The study also highlights the importance of industry-wide collaboration and knowledge sharing in facilitating BIM adoption among SMEs. The authors conclude that BIM adoption requires a coordinated effort between industry stakeholders, including SMEs, government agencies, and industry associations, to promote awareness and understanding of the technology and its benefits. The study provides insights into the factors that impact BIM adoption among SMEs and offers recommendations for industry stakeholders seeking to promote the technology's uptake (Hosseini, 2016).

2.6.8 Case study summery

The review of materials from various nations revealed common advantages and challenges in implementing Building Information Modeling (BIM) in construction projects. BIM is widely used in the design stage, facilitating collaboration, reducing errors, enhancing visualization, improving project scheduling, and enhancing sustainability. However, universal implementation issues were identified, such as resistance to change, high initial investment, lack of standards, skills gap, legal and contractual issues, data management, and security concerns.

To overcome these challenges, experienced BIM users proposed solutions such as education and training, government support and regulations, collaboration and standardization, incremental implementation, and updating legal and contractual agreements. The CoESCoEM Administration Building project will be analyzed and assessed to develop a BIM implementation process for the company and the sector as a whole. The study aims to produce a thorough case study on the CoESCoEM Administration Building and its implementation.

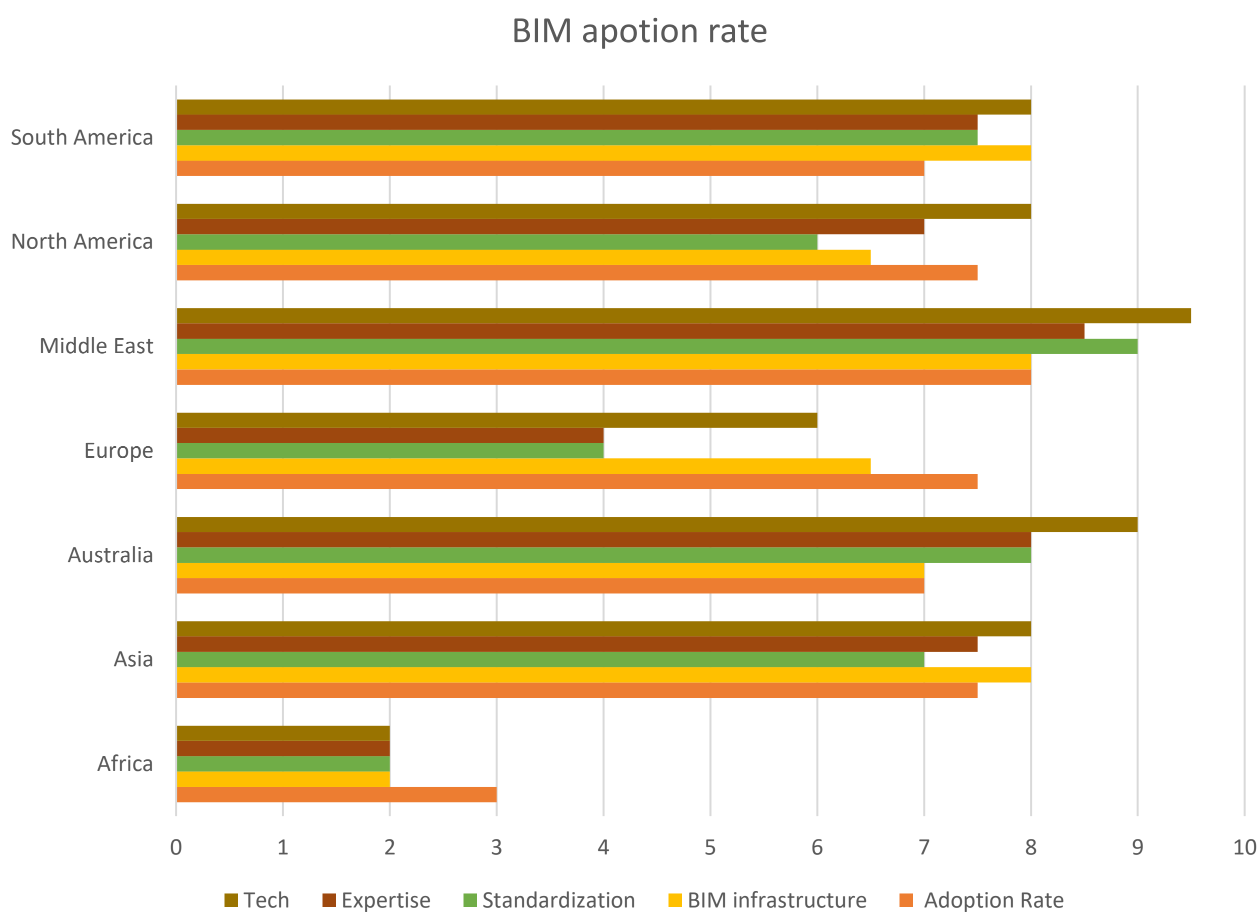

Figure 11 Case study summery

2.9 BIM Implementation in Ethiopia

In the context of Ethiopia's rapidly evolving construction industry, the adoption of Building Information Modeling (BIM) represents a pivotal shift towards modernization and efficiency (Ethiopian Construction Project Management Institute, 2019). This text critically examines the multifaceted landscape of BIM adoption in Ethiopia, drawing insights from recent studies and initiatives. It explores the key obstacles hindering widespread BIM implementation, the educational disparities among AEC students, the potential of BIM to combat corruption, and the proactive efforts of organizations like the Construction Management Institute (CMI). Through an in-depth analysis, this discussion aims to shed light on the challenges and opportunities Ethiopia faces in harnessing the transformative power of BIM within its construction projects, emphasizing the need for a comprehensive and collaborative approach to drive progress in this dynamic sector.

Obstacles to BIM Adoption: While most of the barriers are not unique to Ethiopia, they underscore the importance of addressing foundational issues for successful BIM implementation. Inadequate IT infrastructure, for instance, goes beyond technology; it implies the need for substantial investments in connectivity, digital literacy, and access to hardware and software (Belay, 2021). This realization prompts us to consider the broader digital divide in developing economies and the critical role of governments and international organizations in bridging this gap (Belay, 2021).

The lack of government support is a common challenge faced by emerging BIM markets. However, it also points to the need for a nuanced approach. Governments should not only allocate resources but also create a conducive regulatory environment for BIM adoption. Incentives, standards, and clear guidelines can play a pivotal role in encouraging construction firms to embrace BIM. Moreover, government procurement policies can set a precedent by requiring BIM implementation in public projects, thereby driving its adoption across the industry.

The dearth of BIM research and educational programs suggests a longer-term challenge. Universities and educational institutions must adapt their curricula to meet industry demands (C.Haupt, 2016). However, it also raises questions about knowledge transfer from experienced practitioners to students. Mentorship programs and collaborations between academia and industry can be instrumental in ensuring that graduates are adequately prepared for BIM-enabled practices in the workforce (C.Haupt, 2016).

Educational Disparities and Interdisciplinary Collaboration: A study has revealed a stark contrast in BIM familiarity between architecture and engineering students. While this may initially seem like an academic concern, it has practical implications for the industry (C.Haupt, 2016). Construction projects are inherently interdisciplinary, involving architects, engineers, contractors, and more. Disparities in BIM proficiency could lead to communication breakdowns and inefficiencies. It's crucial to promote cross-disciplinary training and collaboration within educational institutions to mirror real-world project dynamics (C.Haupt, 2016).

The education gap also highlights the need for ongoing professional development (C.Haupt, 2016). As new graduates enter the workforce with varying degrees of BIM expertise, companies should invest in continuous training and upskilling programs. This not only improves project efficiency but also ensures a competitive advantage in the global market, where BIM is increasingly becoming the industry standard (M. Reza Hosseini, 2022).

BIM as a Tool to Combat Corruption: Corruption in construction projects is a pervasive problem globally, and Ethiopia is no exception. BIM's potential to mitigate corruption through real-time project monitoring and transparency offers a novel approach to tackling this issue (Berhe, 2020). However, its success depends on the establishment of robust governance structures and the integration of ethical practices within the industry.

The integration of BIM for project audits and monitoring necessitates careful consideration of data security and privacy (Berhe, 2020). A framework that ensures the integrity and authenticity of BIM data is crucial to prevent fraudulent activities. Moreover, regulatory bodies and industry associations should actively promote ethical practices and provide guidelines for BIM implementation that prioritize transparency and accountability (Berhe, 2020).

CMI's Role and Future Prospects: The Ethiopian Construction Project Management Institute's (CMI) initiatives demonstrate a proactive approach to modernizing the AEC sector. The "training of trainers" (ToT) program, in particular, has the potential to create a sustainable ecosystem of BIM expertise within the country (Tesfaye, 2020). However, the success of CMI's efforts will depend on several factors, including the quality of training provided, the adaptability of the curriculum to evolving BIM technologies, and industry acceptance (Tesfaye, 2020).

Beyond CMI, collaboration with international organizations and experienced BIM practitioners can further accelerate Ethiopia's BIM adoption journey. Knowledge exchange and lessons learned from global BIM implementation can inform best practices and help avoid common pitfalls (Ethiopian Construction Project Management Institute, 2019).

Ethiopia's construction industry is embracing Building Information Modeling (BIM) to improve project outcomes, economic growth, and transparency. However, this requires a holistic approach that includes technology, education, governance, and ethics. The Ethiopian AEC industry needs to develop sector-specific BIM policies and regulations, including a standard contract with BIM protocols, legal provisions, project guidelines, and BIM-compatible procurement methods. Regular trainings, seminars, and workshops are also necessary. A comprehensive strategy is needed to facilitate BIM implementation across public and private projects, and public-private partnership-oriented construction policy schemes should be established. Financial support mechanisms should also be developed, and higher education institutions should include BIM-related courses in their curricula.

2.9.1 Roadmap for adoption and implementation of BIM in Ethiopia

Ministry Of Urban Development and Construction - Construction Management Institute published a document titled: Roadmap for Adoption and Implementation of BIM Technology in The Ethiopia Built Environment Industry (2019), the document outlines a roadmap for the adoption and implementation of Building Information Modeling (BIM) technology in the Ethiopian built environment industry. The roadmap is based on a review of the current state of BIM adoption in Ethiopia, as well as an analysis of the key challenges and opportunities facing the industry (Ethiopian Construction Project Management Institute, 2019).

There are many benefits of BIM technology, including improved collaboration, reduced errors and rework, and enhanced project visualization for the Ethiopian AEC industry (Ethiopian Construction Project Management Institute, 2019).. It then identifies the key challenges to BIM adoption in Ethiopia, such as a lack of awareness and training, limited technical infrastructure, and resistance to change. The roadmap itself is divided into four phases: awareness and education, infrastructure development, pilot projects, and full-scale implementation. During the awareness and education phase, stakeholders in the industry are encouraged to learn about the benefits of BIM and the steps needed to implement it successfully (Ethiopian Construction Project Management Institute, 2019).

The infrastructure development phase involves the establishment of technical infrastructure, such as high-speed internet, necessary for the adoption and use of BIM technology. The pilot projects phase focuses on implementing BIM in small-scale projects to test the technology and identify any issues before full-scale implementation. The final phase is full-scale implementation, where BIM is integrated into all aspects of the built environment industry (Ethiopian Construction Project Management Institute, 2019).

The construction industry in Ethiopia will benefit from to adopting integrated project environments (McCool, 2015). The recommendations include developing a national strategy with a lead agent to coordinate efforts, leveraging the influence of regional states and government agencies, using pilot projects to build a knowledge base, building consensus on standard performance indicators and metrics, developing national standards, investing in shared BIM standards, establishing education programs and incentives for adoption, engaging implementation in all categories of BIM users, and developing meaningful targets for project and built environment performance. These recommendations aim to reduce the macro-economic burden of adoption and increase productivity (Ethiopian Construction Project Management Institute, 2019).

2.7 Literature Gap

Following an extensive and comprehensive survey of case studies and literature reviews conducted across various contexts, it is clear that a major impediment to the widespread adoption of Building Information Modeling (BIM) is the lack of standardization and the absence of a universally accepted workflow. The lack of a standardized framework has, for quite some time, hindered the seamless integration of BIM systems within the domains of design and construction firms. This is evident not because there aren't reference materials but because of a lack of contextually fitting implementation strategies that cater to the unique needs and requirements of each firm.

However, a discernible juxtaposition emerges when comparing scenarios where proper infrastructure, expert knowledge, and standardized processes are readily available. In such environments, BIM systems tend to be more effectively embraced and incorporated. This dichotomy becomes conspicuous when examining a plethora of case studies and perusing the relevant literature. Notably, in those contexts where comprehensive research has been conducted and governmental support has been extended towards BIM initiatives, the implementation of this technology has yielded marked success.

To bridge this conspicuous gap and contribute substantively to the advancement of BIM practices, our research endeavors to create a BIM workflow tailored explicitly for the unique context of the ECDSWC. The study's aim is to craft a workflow that is both streamlined and context-sensitive, thereby setting a precedent that can be universally adopted across the industry. In doing so, we intend to benefit all stakeholders involved. This approach not only addresses the existing void but also lays the foundation for other projects to more efficiently embrace BIM, thus fostering an environment that encourages enhanced collaboration, communication, and, ultimately, the attainment of superior project outcomes. Through these concerted efforts, the study hopes to contribute to the implementation of BIM across multiple projects and aid in the goal of wide BIM adoption in the AEC industry in Ethiopia.

Moreover, it is noteworthy that ISO BIM standards have historically been associated with significant costs for access, thereby limiting accessibility, especially for smaller companies and individuals. The cost for obtaining these documents vary from 160 USD to 180 USD per person & per document (International Organization for Standardization., 2023). This cost barrier can have the unintended consequence of stifling innovation and participation within the sector. Our proposal seeks to rectify this issue by advocating for the creation of openly accessible reference documents. These documents, once available, would serve to accelerate the adoption and implementation of BIM standards, fostering a greater degree of participation and innovation within the construction and infrastructure sectors. This democratization of access is poised to stimulate healthy competition, instigate industry-wide improvements, and promote collaboration and the sharing of knowledge. This, in turn, has the potential to breathe new life into the industry, encourage diversity of ideas, and ultimately drive progress on a significant scale.

Chapter 3: Research Methodology

3.1 Introduction

The methodology for this study encompasses three major parts, each specifically designed to address the three research questions and subsequent research objectives. To assess the experiences of the BIM team and management at ECDSWC, a case study approach is implemented, utilizing data collection methods such as questionnaires, interviews, and observations. Additionally, to evaluate the challenges faced during the transition from the conventional design workflow to the BIM workflow, a comparative approach will be taken. This involves directly comparing the BIM workflow and conventional workflow on different buildings designed simultaneously for the CoESCoEM project. Lastly, the objective of developing a contextually appropriate BIM workflow for ECDSWC will be accomplished by aggregating literature reviews and the findings from the previous objectives. By integrating these diverse sources, a comprehensive and tailored BIM workflow specific to ECDSWC can be formulated. Overall, this structured approach ensures systematic and thorough research, resulting in a refined and coherent output that aligns with the study's overarching objective.

3.2 Research Design

According to Robert K. Yin (1994), this case study research falls under the category of exploratory case study research. Exploratory case studies typically include one or more connected cases and involve steps like gathering, analyzing, and interpreting observations. It is a logical proof model that enables the researcher to infer causal relationships between the variables under inquiry. Exploratory research aims to learn new facts and theories that can be used to solve issues or provide answers in situations that may arise again in the future. It is an essential tool in many disciplines, including the social sciences, business, and sciences (Yin, 2018).

Exploratory research frequently entails gathering information through observation, interviews, or surveys to better understand a subject and pinpoint potential research questions for additional study. When little is known about a topic or the researcher wants to approach the subject from a novel angle, this type of research is especially helpful. The purpose of this study is to investigate the new BIM design workflow being used at ECWDSW and to assess and evaluate how it has been applied to the COESCoEM—Administration Building project (Yin, 2018).

3.3 Research Strategy

For the first objective the case study research involved an analysis of the BIM design workflow and framework at ECDSWC. Data was collected from the project participants through interviews with design teams, observations, and document analysis. The findings from this exploratory case study approach provided valuable insights into the challenges faced and experiences of the project participants, which significantly contributed to formulating a contextually appropriate BIM workflow and framework.

The research assessed the experiences of the BIM team and management at ECDSWC in the CoESCoEM project using a case study approach. Questionnaires, interviews, and observations were conducted to gather both quantitative and qualitative data, enabling a comprehensive understanding of the project's dynamics. Through interviews, participants shared their perspectives on BIM implementation, highlighting key obstacles and successes encountered. The observations provided valuable insights into the practical application of BIM practices and workflows within the organization. This approach allowed for the identification of specific challenges faced during the implementation of BIM and provided insights into the impact of this implementation on the overall design process.

Furthermore, the study specifically focused on documenting and analyzing the challenges encountered technology, processes, and collaboration. To gain a deeper understanding of these challenges.

For the second objective the research design involved the selection of two cases, namely the BIM workflow and the conventional workflow, which were compared based on predetermined objectives and research questions. This careful selection ensured that meaningful comparisons could be made, ultimately providing valuable insights into the topic at hand. In terms of data collection, various sources such as questionnaires, interviews, observations, and document reviews were utilized to gather relevant information. This comprehensive approach enabled the researchers to analyze the collected data and identify patterns, trends, and differences through the application of statistical techniques, qualitative analysis, or a combination of both, thereby facilitating a thorough comparative analysis. Subsequently, the findings from the two cases were synthesized through a cross-case synthesis, aiming to identify commonalities or differences between the BIM workflow and the conventional workflow. Finally, the study delved into a discussion and interpretation of the findings, engaging in a critical reflection on limitations, validity, and reliability, while also addressing potential biases that may have influenced the research outcomes.

The literature review conducted together with the findings is synthesized, leading to a tailored BIM workflow and framework, incorporating best practices and addressing challenges during the transition. The goal is to provide an organized plan to implement BIM at ECDSWC on ongoing and future projects.

3.4.1 Objective 1

To assess the experiences of the BIM team and management at ECDSWC, a case study approach will be implemented. This approach allows for an in-depth exploration of the subject within the ECDSWC for in the CoESCoEM project. The research will employ various data collection methods, including questionnaires, interviews, and observations. The data collection methodology is aimed to identify the experiences of the design team while executing a specific building design project for CoESCoEM project which was the main administration building at the Sendafa campus.

1. Questionnaires were distributed among the BIM team and management at ECDSWC. These questionnaires will contain both closed-ended and open-ended questions to gather quantitative and qualitative data. The closed-ended questions will provide statistical data, while the open-ended questions will allow participants to share their experiences, opinions, and suggestions regarding BIM implementation (Yin, 2018).
2. Interviews In-depth interviews will be conducted with key stakeholders, including BIM team members, project managers, and top-level management. These interviews will delve deeper into the experiences of individuals involved in BIM implementation, allowing for a comprehensive understanding of their perspectives, challenges faced, and lessons learned (Yin, 2018).
3. Observations have been conducted to gain insights into the actual BIM practices and workflows at ECDSWC. Researchers will observe BIM team members and management in action, examining their interactions, decision-making processes, and utilization of BIM tools and technologies. These observations will provide valuable

contextual information and complement the data gathered through questionnaires and interviews (Yin, 2018).

3.4.2 Objective 2

A comparative approach is taken to assess the challenges faced when transitioning from conventional design workflows to BIM workflows. The research will compare the BIM workflow and conventional workflow on different buildings designed simultaneously for the CoESCoEM project. The BIM process was implemented for the administration building, and the conventional approach was taken for a classroom and laboratory buildings. By comparing the two workflows side by side, the research aims to identify the specific challenges encountered during the transition and explore how BIM implementation has affected the overall design process.

1. Context review: This section provides a cohesive overview of the study's context within ECDSWC's building and urban design sector. It begins by presenting the historical and technical background of the company, highlighting its expertise and industry experience. The introduction of the CoESCoEM project follows, emphasizing its aims and objectives and underscoring its significance within the AEC industry in Ethiopia as a whole. Additionally, the background of the client, CMI, is explored to understand their role in the AEC industry in Ethiopia. By encompassing these elements, this section establishes a clear context for the subsequent analysis, enabling readers to grasp the study's context.
2. Tradition workflow Analysis: Analyze In the analysis of the conventional workflow, the research examines the methods and processes employed for designing the classroom and laboratory buildings within the CoESCoEM project. This approach typically involves manual drafting techniques, 2D drawings, and the use of separate design tools for different aspects of the project, such as architectural design, structural analysis, and MEP (mechanical, electrical, and plumbing) systems. The conventional workflow may rely on hand sketches, physical models, and multiple iterations to develop and refine the design. Collaboration among different disciplines and stakeholders might be limited, leading to potential communication gaps and coordination issues.
3. BIM workflow Analysis: Analyze the current BIM design workflow at ECDSWC and the newly established BIM team. Collect data through observation of the team's workflow, reviewing design drawings and documents, and interviews with the BIM team members.

Identify the challenges faced when transitioning from the conventional design workflow to the BIM workflow.

4. Insight and comparisons: By comparing the conventional workflow with the BIM workflow side by side, the research aims to gain valuable insights into the challenges encountered during the transition from conventional methods to BIM. These challenges could include resistance to change, unfamiliarity with BIM software, training requirements, and initial investment in software and hardware. The research also seeks to understand how the implementation of BIM has influenced the overall design process. Potential deductions might include improved coordination, reduced errors, enhanced collaboration, increased efficiency, and streamlined communication among project stakeholders. The findings of this study can provide valuable guidance for organizations considering or undergoing a transition to BIM workflows, facilitating informed decision-making and smoother adoption processes.

3.4.3 Objective 3

Developing a Contextually Appropriate BIM Workflow for ECDSWC The final objective of the research is to develop a contextually appropriate BIM workflow for ECDSWC, taking into account the experiences and challenges identified in the previous objectives. To achieve this, the following methodology will be employed.

1. Literature Review A comprehensive literature review will be conducted, focusing on BIM workflows, technology, and data sharing experiences. This review will help identify best practices, standards, and guidelines for BIM implementation and provide a theoretical foundation for developing the contextually appropriate BIM workflow.
2. Aggregation of Findings The findings from the assessments of BIM experiences and transition challenges, along with the literature review, will be aggregated. By synthesizing these findings, patterns, themes, and recommendations for an effective BIM workflow at ECDSWC can be extracted.
3. BIM Workflow and Framework Development Based on the aggregated findings, a BIM workflow and framework will be developed specifically tailored to the needs and context of ECDSWC. This workflow will incorporate the identified best practices, address the challenges faced during the transition, and leverage the capabilities of available BIM tools and technologies.

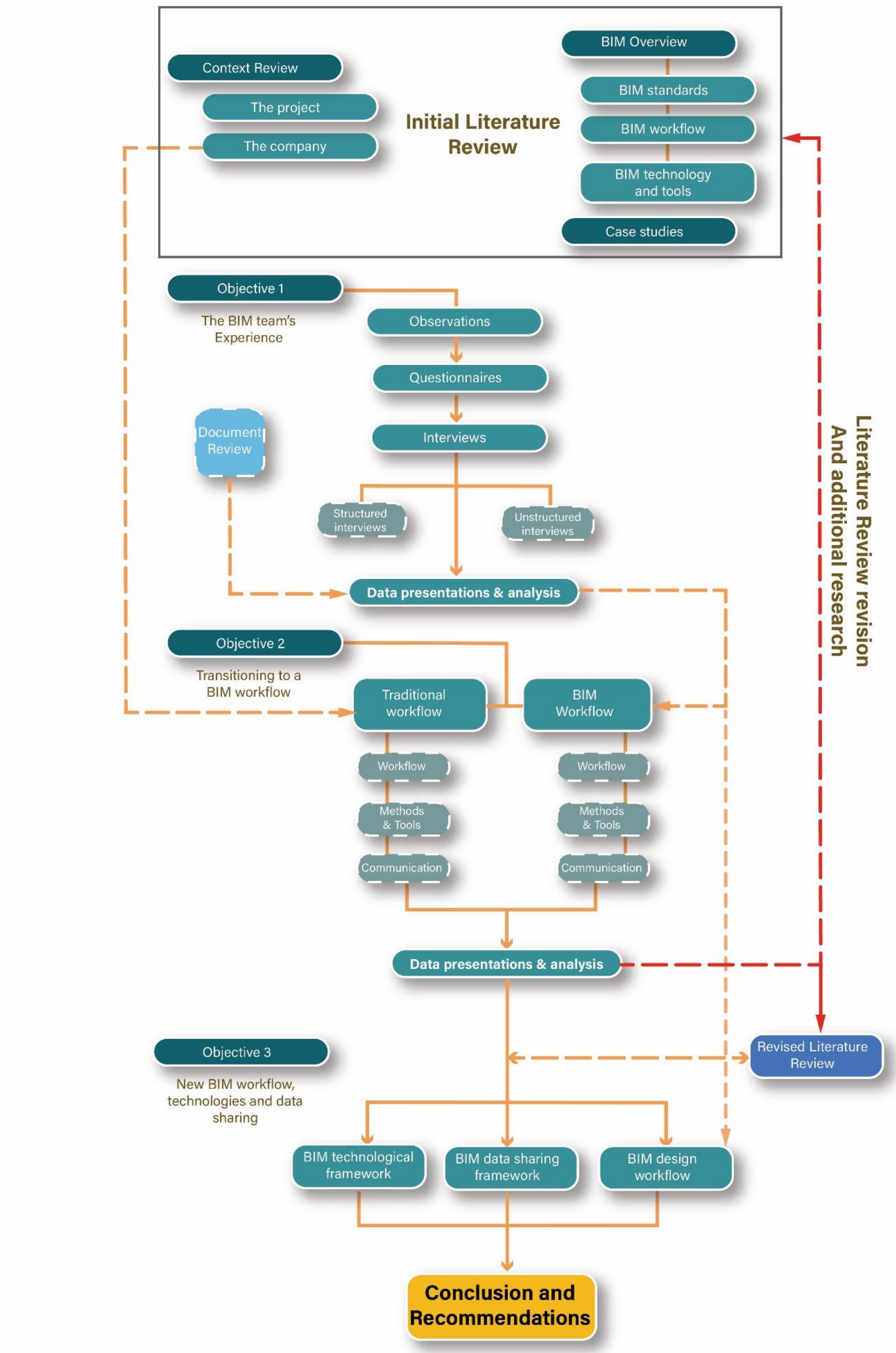

Figure 12 Research metrology chart

3.5 Data Collection and Analysis

To explore the challenges and implications of using BIM at ECDSWC and evaluate the time, quality, and cost advantages of implementing BIM as a design process for the CoESCoEM Administration Building project. Additionally, to assess the viability of using BIM in future projects and evaluate the success of the project using BIM as a design process.

3.5.1 Data Collection Methodology

In this research endeavor, a range of data sources, both primary and secondary, were employed. To begin with, the primary data were gathered, comprising various materials, industry standards, personal observations, notes derived from the case study, as well as interviews and questionnaires. In addition, secondary data sources were also consulted, including relevant literature in the field of Building Information Modelling (BIM) which provided substantial insights to support the research objectives (Yin, 2018).

The data collection methodology aimed to identify the challenges and implications of implementing BIM in the local context, with a particular focus on the CoESCoEM Administration Building project. This was achieved through a rigorous process, involving a comprehensive literature review, project analysis, workflow analysis, a well-designed questionnaire, and personal observations (Yin, 2018).

1. Literature Review: Conduct a review of current literature on the challenges and implications of using BIM in the local context. Also, review prior studies, industry guidelines, publications and ISO standards. Gather insights and perspectives from industry experts on BIM implementation in the local context through interviews.

2. Project Analysis: Understand the CoESCoEM project, its goals, and objectives. Collect and analyze project documents such as the project plan, design brief, and design specifications. Analyze the project data to identify time, quality, and cost advantages of implementing BIM as a design process for the CoESCoEM Administration Building project.

3. Workflow Analysis: Analyze the current BIM design workflow at ECDSWC and the newly established BIM team. Collect data through observation of the team's workflow, reviewing design drawings and documents, and interviews with the BIM team members.

Identify the challenges faced when transitioning from the traditional design workflow to the BIM workflow.

4. Questionnaire: Develop a questionnaire to assess the viability of using BIM in future projects and evaluate the success of the project using BIM as a design process. Collect data from the BIM team members through the questionnaire and analyze the responses.
5. Observation: Being an active participant in the project provided an insider's perspective that enriched the data and contributed to a deeper understanding of the context and the nuances of the case.

3.5.2 Data analysis method

The following are data analysis methods for each category of data collected:

1. Literature Review:
    - Conduct a content analysis of the literature review to identify the challenges and implications of using BIM both internationally and locally.
    - Identify common themes and patterns from the literature and summarize them.
    - Compare the findings from the literature review and the interviews to identify any discrepancies or contradictions.
2. Project Analysis:
    - Conduct a comparative analysis of the project data to identify the time, quality, and cost advantages of implementing BIM as a design process for the CoESCoEM Administration Building project.
    - Summarize the findings of the project analysis and identify any issues or limitations that might have affected the results.
3. Workflow Analysis:
    - Conduct a thematic analysis of the data collected through observation, reviewing design drawings and documents, and interviews with the BIM team members.
    - Identify the challenges faced when transitioning from the traditional design workflow to the BIM workflow.
    - Summarize the findings of the workflow analysis and identify any opportunities for improvement in the BIM workflow.

4. Questionnaire:

    - Conduct a descriptive analysis of the responses collected from the BIM team members through the questionnaire.
    - Analyze the insights and perspectives gathered from project stakeholders regarding the BIM implementation through interviews.
    - Summarize the findings of the questionnaire and identify any trends or patterns in the data.
    - Compare the findings of the questionnaire interviews and observation and present the results.

5. Observation:

    - Use the insights and perspectives gained from being an active participant in the project to enrich the analysis of implementing BIM on the CoESCoEM project.
    - Summarize the findings of the observation and incorporate them into the analysis.

6. Integration:

    - Integrate the findings from each data source to provide a comprehensive analysis of the challenges and implications of implementing BIM, with a particular focus on the CoESCoEM Administration Building project.
    - Identify any gaps or inconsistencies in the findings and provide recommendations for future research.

3.6 Validity and Reliability

The validity and reliability of case study research are important considerations for this research. Validity refers to the accuracy of the research findings, while reliability refers to the consistency of the findings (Yin, 2018). In this study, the validity of the case study approach is ensured by the research has been conducted using appropriate methods and techniques that capture the complexity of the project being studied and the actual experiences of project building design participants. This is done by using a combination of quantitative and qualitative data collection methods, triangulation, and standardized protocols and guidelines for data collection.

Reliability, on the other hand, refers to the consistency and dependability of the research findings and conclusions. (Yin, 2018). Reliability is ensured by using a rigorous and systematic approach to data collection and analysis, and by ensuring that the data is collected from multiple sources over the project design phase. This is done by using systematic and rigorous data analysis techniques that are appropriate for the research questions and data collected, and by ensuring that the analysis is conducted consistently across the study.

In addition to validity and reliability, it is also important to address the researcher's reflexivity and bias in case study research. As an active participant in the focus of the study, a potential influence of researcher bias on the research process and findings may occur. In order to mitigate this and take steps to minimize their impact on the results and findings, the researcher engaged in reflexivity, which involves acknowledging limitations and examining biases and assumptions throughout the research process. The researcher also interpreted the findings in a balanced and unbiased manner by considering alternative explanations on certain topics. By following these guidelines, this research aims to ensure the validity, reliability, and trustworthiness of the findings, recommendations, and conclusions.

3.7 Limitations of the study

BIM implementation is a cyclical process that starts with the building conception phase and continues throughout the construction and lifecycle management of the structure. The process requires continuous communication and collaboration between the designers, engineers, contractors, and facility managers. The CoESCoEM Administration Building project is a significant undertaking that involves several years of design, construction, and operation phases. Given the time constraints of this study, it is not possible to observe and report on the complete BIM implementation process. Therefore, this research will solely focus on the design and documentation aspects of BIM integration in this specific project.

The design phase of BIM implementation involves stakeholders working together to develop the project's scope, goals, and objectives. BIM software is used to create 3D models of the building that can be modified and updated. The documentation phase involves the creation and management of project documentation, which ensures all stakeholders have access to the latest project information. BIM software automatically updates project documents as changes occur in the digital model, reducing the risk of errors and delays.

Future studies can leverage this research as a starting point to further analyze and scrutinize the complete BIM process across the design, construction, and operation phases. Understanding the benefits of BIM implementation and its challenges will help stakeholders improve their approach to managing complex construction projects, resulting in increased efficiency, reduced costs, and improved project outcomes (Diaz, 2016). In conclusion, the BIM implementation process is a continuous and iterative process that encompasses the entire life cycle of a building. Despite the constraints of this study, the research conducted in this specific project provides valuable insights into the design and documentation aspects of BIM integration. By leveraging this research as a foundation for future studies, stakeholders can gain a more comprehensive understanding of BIM implementation and its role in managing complex construction projects.

3.7 Chapter summary

This study is aimed at evaluating and studying the implementation of Building Information Modelling (BIM) in the Center of Excellence for Sustainable Construction Engineering and Management (CoESCoEM) Administration Building. The methodology is organized into four main topics: research design, research strategy, data collection and analysis, and data analysis method. The research design falls under the category of exploratory case study research, which involves one or more connected cases and steps like gathering, analyzing, and interpreting observations. The purpose of this study is to investigate the new BIM design workflow being used at ECWDSW and to assess and evaluate how it has been applied to the COESCoEM—Administration Building project. The research strategy involves examining current literature from a variety of sources, understanding what the CoESCoEM project aims to achieve, studying and evaluating the current design workflow at ECDSWC and the newly established BIM team, and using a questionnaire to assess the BIM team's experience while working on the CoESCoEM project.

The data collection methodology involves gathering both primary and secondary data, such as project documents, personal observations, notes derived from the case study, interviews, and questionnaires. The data collection methodology aims to identify the challenges and implications of implementing BIM in the local context, with a particular focus on the CoESCoEM Administration Building project. The data analysis method includes categorizing and coding the data, creating charts and graphs, and using statistical software to analyze the data collected through the questionnaire. The aim is to investigate the challenges and implications of using BIM in the local context and evaluate the time, quality, and cost advantages of implementing BIM as a design process for the CoESCoEM Administration Building project. Additionally, to assess the viability of using BIM in future projects and evaluate the success of the project using BIM as a design process.

The methodology used in this research study is aimed at systematically and thoroughly evaluating the implementation of BIM in the CoESCoEM Administration Building project, ensuring accurate and reliable results, and respecting the rights of the participants. The study will also provide recommendations for the improvement of BIM implementation in future projects and highlight the benefits and challenges of using BIM as a design process. Overall, this research study will contribute to the advancement of BIM technology at ECDSWC and the construction industry as whole.

Chapter 4- Context Review

4.1 Introduction

This chapter will provide an overview of the Centre of Excellence for Sustainable Construction Engineering and Management (CoESCoEM) project proposed by the Construction Management Institute (CMI). The project is aimed at improving the capacity and sustainability of the Ethiopian construction industry by providing the necessary infrastructure, equipment, and human resources to develop an internationally competitive construction industry. The proposed center will include research, training, mock-up, and centralized materials testing facilities, among others. The CoESCoEM project is a significant step towards achieving the 10-year strategic plan of the sector and the targets set over the 30-year roadmap of the sector. The establishment of the Construction Center of Excellence is expected to contribute to the development of a competitive construction industry and promote import substitution to ensure a reliable supply of the backward linkage. Additionally, it is designed to contribute to quality assurance and ethical performance improvement in the construction industry. The project is expected to improve the professional capacity of graduates, local contractors, and consultants in the construction industry through hands-on training and introduction to advanced technologies (Ethiopian Construction Project Management Institute, 2021).

ECDSWC is a highly reputable and experienced company in the field of construction and engineering. They have a proven track record of successfully delivering projects of similar scope and complexity. Their team of experts comprises some of the most skilled and knowledgeable professionals in the industry. Given their expertise and experience, ECDSWC was deemed the best fit for the project, and the decision to choose them was made after careful consideration and evaluation.

4.2 Background of ECDSWC

4.2.1 Brief History

ECDSWC since its inception has gone through several changes and names throughout the years. It all started with a group of Swedish Volunteers Services (SVS) and a group of Ethiopian University Service Students from the Building College back in the early sixties. The group built the first school in Zwał Town. SVS then continued building other schools all over country until the middle of the 60's when it was reconstituted as the ESBU (Elementary School Building Unit), which was established in 1971. Then it changed to RPA (Regular Projects Agency) in 1975, then to EBCA (Ethiopian Building Construction Authority) in 1980, then to CDE (Construction Design Enterprise) in 1985, then to BDE (Building Design Enterprise) in 1987, then to CDSC (Construction Design Share Company) in 2002, and finally to ECDSWC (Ethiopian Construction Design & Supervision Works Corporation) in 2005 (Kebede, 2023).

Ethiopian Construction Design & Supervision Works Corporation (ECDSWC) is a multi-disciplined engineering company that was established by the merger of three companies: Water Works Design and Supervision Enterprise (WWDSE), Construction Design Share Company (CDSC), and Transport Construction Design Share Company (TCDSC), which had been active in the planning, study, design, and supervision of water and hydropower, building, and transport sector works since 1998, 1977, and 1987, respectively. The ECDSWC is now a fully integrated engineering consulting firm offering consultancy services with six business units in the fields of water and energy, building and urban planning, transport, geotechnics, and underground works. These business units are supported by two fully organized and dedicated centers: one with advanced laboratory and research and the other with surveying, geospatial, and civil informatics in search of excellence and quality. Quality and excellence are more important to ECDSWC (Ethiopia Construction Design and Supervision Works Corporation, 2016).

4.2.1 Organizational structure

ECDSEC is a large, multi-disciplined engineering company. The structure is so elaborate that it is highly detailed and complex. This complexity is necessary in order for the company to successfully execute a variety of complex projects in-house. As ECDSEC is a multi-disciplined company, it has expertise in a range of engineering fields, allowing it to take on projects that require diverse skill sets. Overall, the organizational structure and expertise enable a company to effectively carry out complex projects (Ethiopia Construction Design and Supervision Works Corporation, 2016).

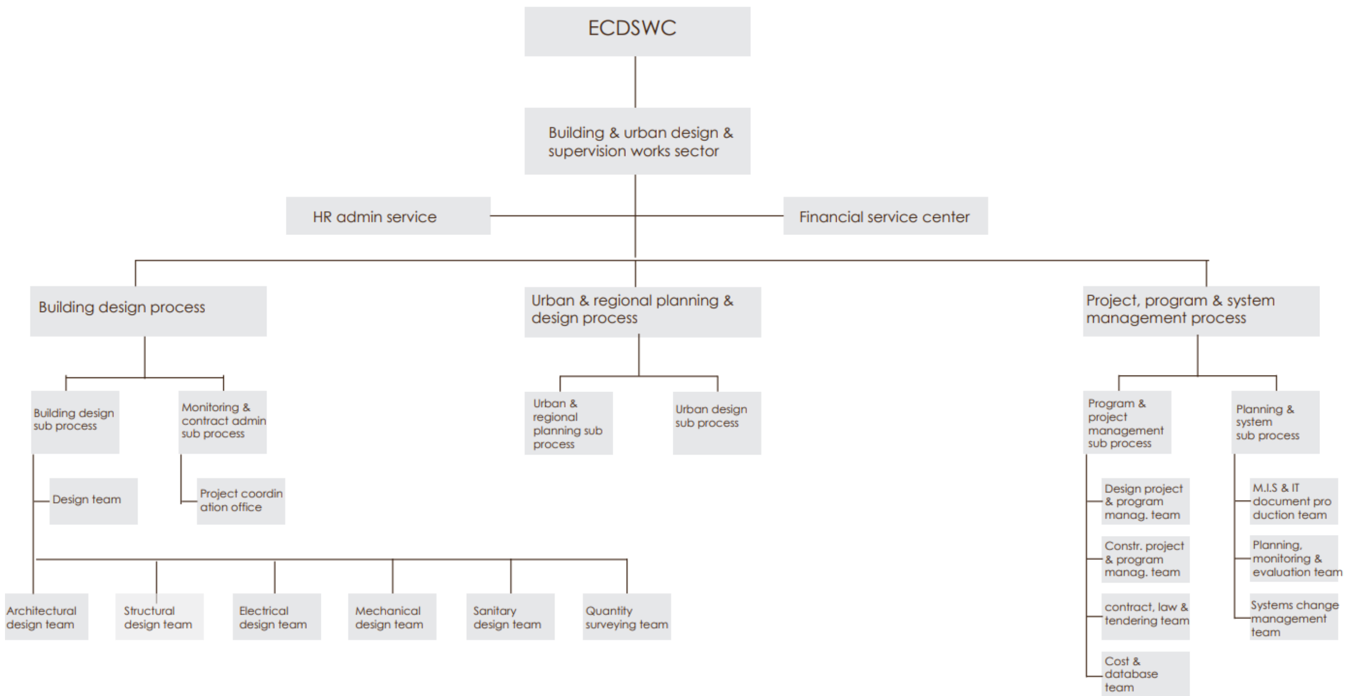

Figure 13 Building and urban design and supervision works sector organizational structure

4.2 Background of CMI

The Construction Management Institute (CMI) is a federal institution responsible for improving the country's construction project management capabilities, operating under the Ministry of Urban Development and Construction (MoUDC) since 2007. The CMI has achieved various milestones, including the publication of the Ethiopian Construction Project Management Manuals Series, training over 12,500 industry professionals in construction management, providing consultancy services to different federal bodies, participating in the formulation of the Federal Government Public Projects Administration and Management System Proclamation, piloting and introducing BIM technology, and preparing the Ethiopian CPM Code of Standards. The institute has put in place the necessary infrastructure, genuine software, and internationally certified BIM trained professionals to facilitate the adoption and implementation of BIM technology in the Ethiopian construction industry. The CMI is accountable to the Ministry and has made significant contributions to the development of the country's construction industry (Ethiopian Construction Project Management Institute, 2021).

The Centre of Excellence for Sustainable Construction Engineering and Management (CoESCoEM) project is a proposal by the Construction Management Institute (CMI) aimed at addressing the lack of well-established institutional set-ups in the Ministry of Urban Development and Construction (MoUDC) in Ethiopia. The project is a crucial step towards fulfilling the mandates of MoUDC, which include designing long-term strategic plans for the construction sector, regulating construction works, determining construction work standards, and establishing transparent and accountable systems for the management of design, bidding, and contract contents (Ethiopian Construction Project Management Institute, 2021).

4.3 The CoESCoEM project

The CoESCoEM project has been chosen as a case for this study because it is one of the large-scale projects in scope that is aiming to utilize BIM implementation in its design phase. As CMI itself is stiving towards a better construction industry in Ethiopia the implementation of BIM seemed evident, by designing and constructing the excellence center by using appropriate systems and technologies such as BIM,, CMI intended to lead by example and demonstrate the benefits of BIM to other construction projects in the country. The CoESCoEM project served as a perfect opportunity for CMI to showcase the advantages of BIM, such as improved collaboration, reduced errors, and enhanced project efficiency. By successfully implementing BIM in this large-scale project, CMI aimed to inspire other stakeholders in the construction industry to embrace this innovative technology and drive positive change in the sector.

CoESCoEM is envisioned as a full-fledged research center, training center, mock-up center, and centralized materials testing center, among other facilities, which would enable the construction sector in Ethiopia to achieve the goals and purposes for which it was primarily established. The proposed center would provide the industry with the required facilities, equipment, and human resources to enhance its capacity and sustainability and ultimately develop an internationally competitive construction industry.

The CoESCoEM project is therefore an essential initiative by CMI, in collaboration with academia and other research institutions, to capacitate industry actors and address the challenges faced in the sector. It is a significant step towards achieving the 10-year strategic plan of the sector and the targets set over the 30-year roadmap of the sector.

4.3.1 General Information

Name of Proposing Public Body	Ministry Of Urban development and Construction /Construction Management Institute (CMI)
Responsible Line Ministry	Ministry Of Urban development and Construction
Name of Project	Construction of Center of Excellence for Sustainable Construction Engineering & Management (CoESCoEM) - Construction Industry Reform Project
Location	At Sendafa Oromia, Ethiopia
Design consultant	Ethiopian Construction Design and Supervision Works Corporation (ECDSWC)
Sources of Capital Funding	Government Treasury

Table 1Genral Information about the project

The establishment of the Construction Center of Excellence for Sustainable Construction Engineering & Management (CoESCoEM) aims to contribute to the development of a competitive construction industry through: building the capacity of the construction industry; promoting import substitution to ensure reliable supply of the backward linkage; promoting construction quality, time, and cost performance; improving the multiplier effects of the industry; and economic structural transformation (Ethiopian Construction Project Management Institute, 2021).

The center of excellence is being created as a model for enhancing and developing actors' performance capabilities in order to ultimately improve the competitiveness of the construction industry (Ethiopian Construction Project Management Institute, 2021).

In order to verify the quality of input materials before including them in construction projects, improve the quality of construction outputs, and lower project lifecycle costs, this is intended to make a significant contribution to quality assurance and ethical performance improvement in the construction industry (Ethiopian Construction Project Management Institute, 2021).

This CoESCoEM project is designed to support deliberate, well-managed, and ongoing construction industry development efforts in order to address these challenges sustainably. By doing so, it will maximize the Ethiopian construction industry's contribution to meeting national construction demand, advancing national social and economic development goals, and fostering industry performance (Ethiopian Construction Project Management Institute (ECPMI), 2021).

4.3.2 Aim and purpose of the CoESCoEM project

The Ethiopian construction industry has faced criticism for its poor performance due to the absence of reliable quality assurance facilities locally, resulting in projects with functionality issues and warranty problems. The lack of competent and ethical local firms has also led to foreign firms carrying out substantial domestic construction projects. The Construction Management Institute was established to bridge project management gaps by conducting skill development training but lacks facilities for material testing and accreditation services. Establishing a center of excellence would provide the necessary facilities for testing, accreditation, and skill development, contributing to the enhancement of local firms' competitiveness. Ethiopia has been investing in institutions and human resources skills development in the construction sector but has not achieved expected socio-economic objectives or harnessed technological development potential. The CoESCoEM project is designed to address these challenges and sustainably develop the Ethiopian construction industry to meet national demand, promote social and economic development, and improve industry performance and competitiveness (Ethiopian Construction Project Management Institute, 2021).

These are the main purpose of the CoESCoEM institute:

- The project aims to improve the professional capacity of at least 120,000 graduates, 10,000 local contractors, and 300 local consultants in the construction industry through hands-on training and introduction to advanced technologies.
- The project emphasizes the use of renewable energy sources and environmentally friendly building materials.
- The project aims to strengthen the university-industry linkage and benefit TVET institutions, construction bureaus, and construction materials and equipment producers.
- The project is expected to contribute to the efficient execution of projects, the growth of the economy, and the improvement of alternative dispute resolution mechanisms in the AEC.
- Trainees will be supported with advanced digital teaching aids, including smart TVs with internet connections and multifunctional digital cameras.

- Hands-on training will be given on complex design preparations through state-of-the-art software, including interior designs, acoustic designs, landscape designs, producing green building designs, etc.
- Trainings on various civil engineering disciplines will be supplemented with the latest design software (structural, geotechnical, etc.).
- Project management practical hard- and software-based trainings will be provided (contract administration, value engineering, quantity surveying, project valuation, Primavera, etc.).
- Project formulation and management for mega projects will be covered.
- Local courts will benefit from the implementation of the project by serving as an incubation center for promoting alternative dispute resolution mechanisms and also as an independent institution to give reliable and independent expert opinions for subsequent court proceedings.

4.3.3 Site and context

On September 17, 2022, the Design Team at ECDSWC conducted a site visit to Sendafa, Oromia Ethiopia. Situated 38 kilometers from Addis Ababa and 2 kilometers from Sendafa town, the site spans approximately 14.2 hectares without any significant structures nearby. This visit allowed the team to directly assess the site's infrastructure, utilities, topography, and surrounding environment, gathering valuable data in the process.

The site visit proved to be a crucial undertaking for the design team, offering them an opportunity to delve deeper into the project's requirements and gain a comprehensive understanding of the site's characteristics. Engaging with clients and exploring the feasibility and potential impact of the proposed design were key objectives accomplished during this visit.

By adopting a holistic approach to the site visit, the design team ensures that the final design will be both functional and sustainable, aligning with the client's needs and surpassing their expectations. This thorough exploration of the site paves the way for a successful and well-informed design process.

Figure 14 The BIM team at the site Visit, Sendafa

Figure 15 Site Pictures

Figure 16 Site Picture at Sendafa

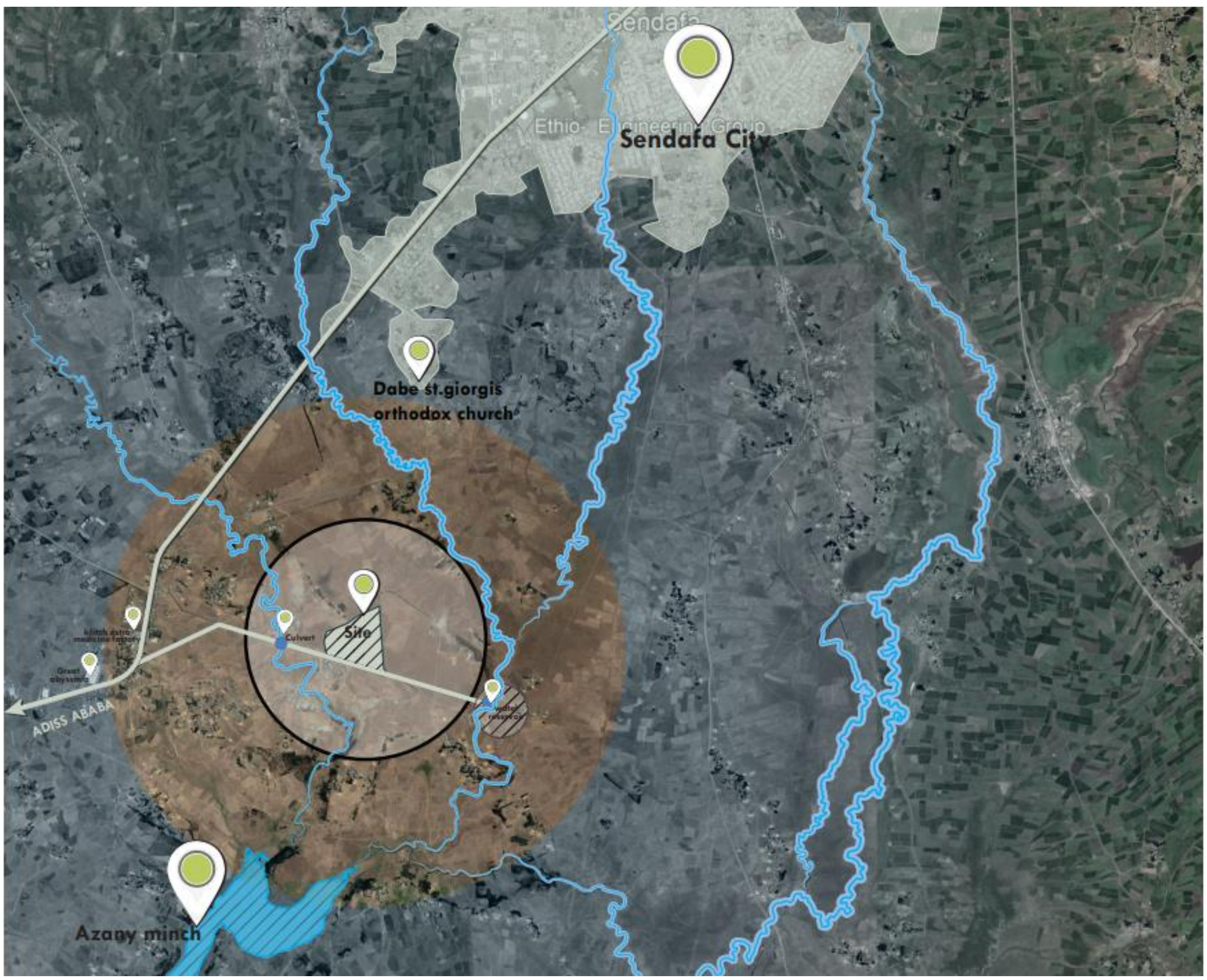

Figure 17 Site and its general Context

4.3.4 Project Schedule

Initially, the CoESCoEM project was allocated a reasonable amount of time for execution, with approximately 8 months from March 2nd to December 20th. However, due to several administrative and contractual issues, the actual time for project execution time was significantly reduced. The project had only 20 weeks from August 3rd to December 20th, which included all pre-design preparations such as team training, workspace preparation, and acquiring software and hardware. This meant that the design schedule was highly compressed, and some predesign preparation tasks were undertaken in parallel to salvage whatever time was available.

Despite the best efforts of the project team, there were still weeks where the BIM team was idle due to several technical and administrative issues. This idle time impacted the design process and made it more challenging to meet the project's deadlines. For the building design phase, the team had a total of 60 days for the first iteration based on the initial master plan layout, from September 14th to October 18th. The first iteration of the design was developed based on a preliminary master plan layout, and the team had to work quickly to refine it and ensure that it met the project's requirements. After completing the first iteration of the design, the team had to work on the second iteration based on the revised master plan layout. The team had from November 24th to December 20th to complete the second iteration of the design, which meant they had to work very quickly and efficiently to meet the project's tight deadlines. Overall, the CoESCoEM project faced significant time constraints due to various issues that impacted the project's design and execution. However, the project team was able to work together to overcome these challenges and deliver a high-quality building design that met the project's objectives. Despite the challenges aced during the project, the CoESCoEM project serves as an example of how to successfully execute a complex project under tight time constraints.

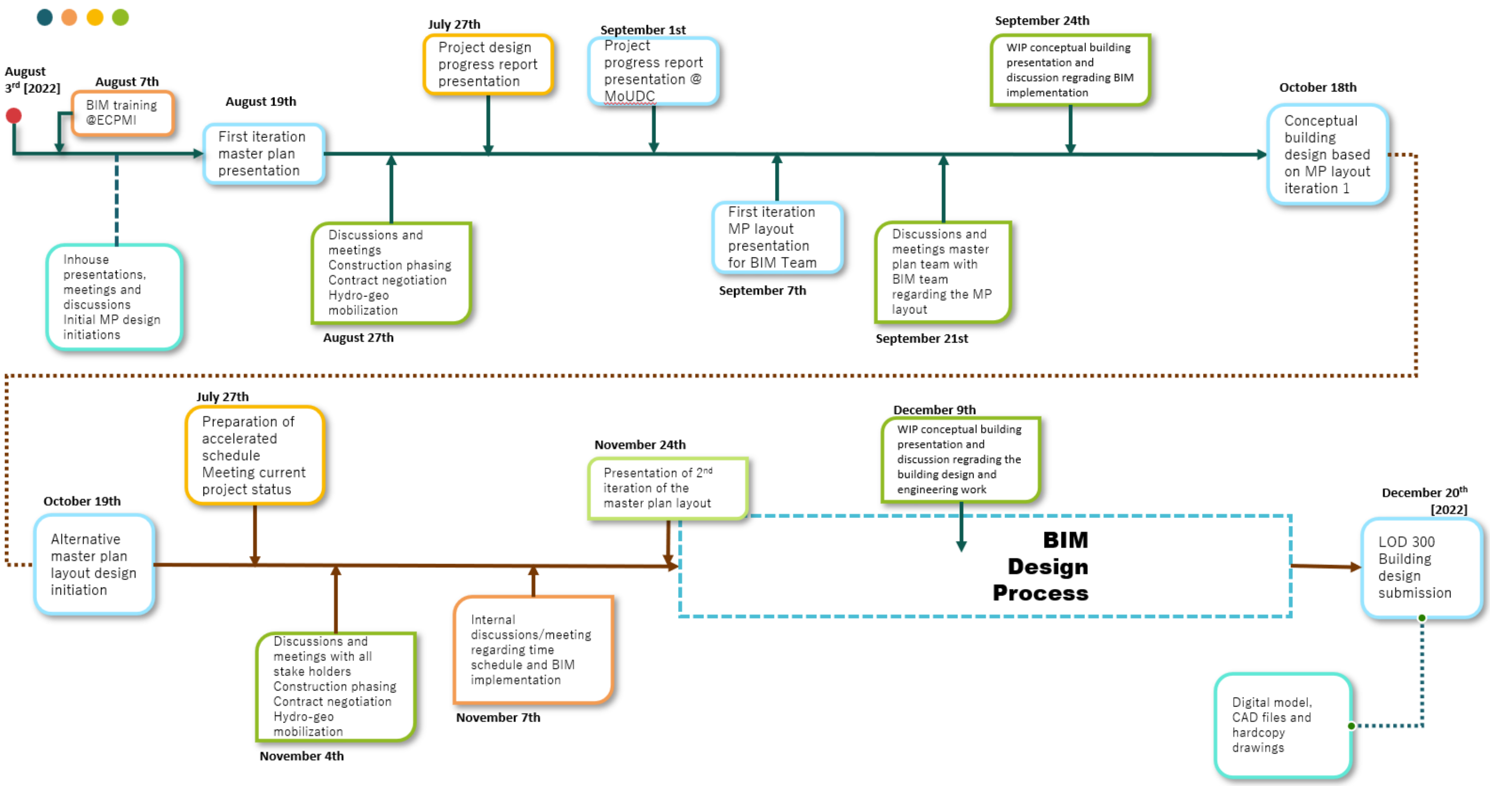

Figure 18 Actual timeline

Project : Construction Centre of Excellence and Laboratory(CCEL)

Contract Number: 05\2011

Project Code : D9-002/2011

Tentative Project Work plan

Key

- Presentation and feedback period
- Tasks Started
- Tasks Completed

Schedule Revision Date: **17th June 2022**

Prepared By: **Yitbarek A.**

Component No	Project Components	Component Share [%]		Draft Project Work Plan & Accompanying Activities	Milestone Activity Weight [%] Component Share	Milestone Activity Weight [%] Overall Share	July W1	July W2	July W3	July W4	August W1	August W2	August W3	August W4	September W1	September W2	September W3	September W4	October W1	October W2	October W3	October W4	November W1	November W2	November W3	November W4	December W1	December W2	December W3	December W4	January W1	January W2	January W3	January W4	February W1	February W2	February W3	February W4	March W1	March W2	March W3	March W4
1	Topographic Surveying	2	1.1	Preparation Work	5	0.08	0.08																																			
			1.2	Field Activities	70	1.12		0.56	0.56																																	
			1.3	Map Preparation	20	0.32				0.32																																
			1.4	Report Production	5	0.08				0.08																																
2	Geotechnical Investigation	11	2.1	Preparation Work	5	0.55	0.55																																			
			2.2	Field Activities	70	7.70		3.85	3.85																																	
			2.3	Map Preparation	20	2.20				2.20																																
			2.4	Report Production	5	0.55				0.55																																
3	ESIA Study	4	3.1	Preparation Work	5	0.20	0.20																																			
			3.2	Field Activities	70	2.80		1.40	1.40																																	
			3.3	Office Work	5	0.20				0.20																																
			3.4	Report Production	20	0.80				0.80																																
4	Hydrogeological Investigation	2	4.1	Preparation Work	5	0.10	0.10																																			
			4.2	Field Activities	70	1.40		0.70	0.70																																	
			4.3	Lab. Test Activities	5	0.10				0.10																																
			4.4	Report Production	20	0.40				0.40																																
5	Master Plan Preparation	18	5.1	**Pre-Design Study**	16	2.88																																				
			5.1.1	Site visit & Project cick off	2	0.36	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05																												
			5.1.2	Document Review & Compilation	2	0.36	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05																												
			5.1.3	Physical and spatial data collection and analysis	4	0.72	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09																												
			5.1.4	ESIA data collection and analysis	3	0.54	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07																												
			5.1.5	Pre-design study summary	2	0.36	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05																												
			5.1.6	Program of accomodation development and analysis	3	0.54	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07																												
			5.2	**Schematic Design**	21	3.78																																				
			5.2.1	Vision, Goal and Principle Setting	2	0.36									0.09	0.09	0.09	0.09	Presentation																							
			5.2.2	Concept Development	5	0.90									0.23	0.23	0.23	0.23																								
			5.2.3	Schematic Master Plan Layers	8	1.44									0.36	0.36	0.36	0.36																								
			5.2.4	Graphics Illustration & Presentation	6	1.08									0.27	0.27	0.27	0.27																								
			5.3	**Preliminary Design**	32	5.76																																				
			5.3.1	Detailing Master Plan Layers	16	2.88														0.58	0.58	0.58	0.58	0.58	Presentation																	
			5.3.2	Detail 3D Modeling, illustrations& animaton	10	1.80														0.36	0.36	0.36	0.36	0.36																		
			5.3.3	Draft Design guidelines	3	0.54														0.11	0.11	0.11	0.11	0.11																		
			5.3.4	Draft Development/Implementation Strategies	3	0.54														0.11	0.11	0.11	0.11	0.11																		
			5.4	**Final Design**	30	5.40																																				
			5.4.1	Updating & Refining Master Plan Layers	12	2.16																			Presentation	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27									
			5.4.2	Final Design guidelines	6	1.08																				0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14									
			5.4.3	Final Development/Implementation Strategies	4	0.72																				0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09									
			5.4.4	Development/Implementation Cost Estimation	3	0.54																				0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07									
			5.4.5	Report Production	5	0.90																				0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11									
6	Landscape Design Preparation	14	6.1	**Pre-Design Study**	14	1.93																																				
			6.1.1	Site Visit and kick off	2	0.28	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03					Presentation																							
			6.1.2	Physical and spatial data collection and analysis	5	0.69	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09																												
			6.1.3	Enviromental data collection and analysis	2	0.28	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03																												
			6.1.4	Pre-design study summary	4	0.55	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07																												
			6.1.5	Program of accomodation development and analysis	3	0.41									0.10	0.10	0.10	0.10																								
			6.2	**Schematic Design**	24	3.31																																				
			6.2.1	Setting Vision, goals and principles	4	0.55														0.11	0.11	0.11	0.11	0.11	Presentation																	
			6.2.2	Concept Development	6	0.83														0.17	0.17	0.17	0.17	0.17																		
			6.2.3	Schematic Site layout	10	1.38														0.28	0.28	0.28	0.28	0.28																		
			6.2.4	Graphics Illustration & Presentation	4	0.55														0.11	0.11	0.11	0.11	0.11																		
			6.3	**Design Development**	32	4.42																																				
			6.3.1	Revised site layout	6	0.83																				0.17	0.17	0.17	0.17	0.17	0.17	Presentation										
			6.3.2	Grading Plan + Sections	5	0.69																				0.14	0.14	0.14	0.14	0.14	0.14											
			6.3.3	Hardscaping Plan + Details	5	0.69																				0.14	0.14	0.14	0.14	0.14	0.14											
			6.3.4	Planting Plan + Plant catalogue	4	0.55																				0.11	0.11	0.11	0.11	0.11	0.11											
			6.3.5	Landscape Amenities [plan + elevation + section]	4	0.55																				0.11	0.11	0.11	0.11	0.11	0.11											
			6.3.6	Drainage + Irrigation Layout	3	0.41																				0.08	0.08	0.08	0.08	0.08	0.08											
			6.3.7	Site Electrification + Lighting Layout	3	0.41																				0.08	0.08	0.08	0.08	0.08	0.08											
			6.3.8	2D + 3D Illustration + Presentation	2	0.28																				0.06	0.06	0.06	0.06	0.06	0.06											
			6.4	**Construction Document**	30	4.14																																				
			6.4.1	Demolition Plan	1	0.14																											0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
			6.4.2	Final site layout	4	0.55																											0.09	0.09	0.09	0.09	0.09	0.09	0.00	0.00	0.00	0.00
			6.4.3	Final Grading Plan + Sections	3	0.41																											0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.00	0.00	0.00
			6.4.4	Hardscaping Plan + Details [plan + elevation + section]	4	0.55																											0.09	0.09	0.09	0.09	0.09	0.09	0.00	0.00	0.00	0.00
			6.4.5	Planting Plan + Plant catalogue + Planting schedule	3	0.41																											0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.00	0.00	0.00
			6.4.6	Landscape Amenities [plan + elevation + section]	3	0.41																											0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.00	0.00	0.00
			6.4.7	Drainage System Design + Irrigation System Design	2	0.28																											0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
			6.4.8	Site Electrification Design + Lighting Design	2	0.28																											0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
			6.4.9	2D + 3D Illustration + Presentation	2	0.28																											0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
			6.4.10	Material Specification	2	0.28																											0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
			6.4.11	Priced and non-priced BoQ	2	0.28																											0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
			6.4.12	Construction Tender Document	2	0.28																											0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
	Building design preparation	47	7.1	**Pre-Design Study**																																						
			7.1.1	Site Visit and kick off			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					Presentation																							
			7.1.2	Physical and spatial data collection and analysis			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																												
			7.1.3	Pre-design study summary			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																												
			7.1.4	Program of accomodation development and analysis											0.00	0.00	0.00	0.00																								
			7.2	**Schematic Design**																																				
			7.2.1	Concept Development																0.00	0.00	0.00	0.00	0.00																		
			7.2.2	Schematic Site layout																0.00	0.00	0.00	0.00	0.00																		
			7.2.3	Graphics Illustration & Presentation																0.00	0.00	0.00	0.00	0.00																		
			7.4	**Design Development**																																				
			7.4.1	Architectural Design																						0.00	0.00	0.00	0.00	0.00	0.00	Presentation										
			7.4.2	Structural Design																						0.00	0.00	0.00	0.00	0.00	0.00											
			7.4.3	Mechanical Design																						0.00	0.00	0.00	0.00	0.00	0.00											
			7.4.4	Electrical Design																						0.00	0.00	0.00	0.00	0.00	0.00											
			7.4.5	Sanitary Design																						0.00	0.00	0.00	0.00	0.00	0.00											
			7.4.6	Material Specification																						0.00	0.00	0.00	0.00	0.00	0.00											
			7.4.7	Non-priced BoQ																						0.00	0.00	0.00	0.00	0.00	0.00											
			7.4	**Construction Document**																																				
			7.4.1	Architectural Design																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.4.2	Structural Design																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.4.3	Mechanical Design																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.4.4	Electrical Design																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.4.5	Sanitary Design																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.4.6	Material Specification																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.4.7	Priced and non-priced BoQ																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			7.5.7	Tender Document																													0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physical Project Progress [Weekly Basis]							1.51	7.09	7.09	5.23	0.58	0.58	0.58	0.58	1.05	1.05	1.05	1.05	0.00	1.81	1.81	1.81	1.81	1.81	0.00	1.56	1.56	1.56	1.56	1.56	1.56	0.68	1.37	0.69	0.69	0.69	0.69	0.69	0.00	0.00	0.00	0.00
Physical Project Progress [Monthly Basis]							20.94				2.34				4.19				5.44				5.19				6.23				4.29				2.76				0.00			
Physical Project Progress [Yearly Basis]							51.38																																			

Table 2 Intended CoESCoEM project schedule

Chapter 5- Data Presentation and Synthesis of Findings

5.1 Introduction

The In this case study, the research methodology was designed to embrace the principles of ethnographic research, involving a holistic approach to data collection and analysis. The data collection process comprised interviews with key stakeholders, rigorous document analysis, and extensive observational work. These approaches helped the researcher understand the organizational structure and contextual intricacies of the study subject. The analysis was conducted using both deductive and inductive approaches. The deductive approach drew upon existing literature and research questions as a foundation. Meanwhile, the inductive approach allowed for new themes and categories to organically emerge from the rich, context-specific data. This methodological flexibility ensured that the study remained open to the nuances and complexities of the research context.

To fulfill the research objectives, a qualitative research approach was employed. This approach facilitates a deeper understanding of the studied phenomenon. Data were meticulously gathered from a diverse set of sources, including in-depth interviews with key stakeholders, thorough document analysis, and keen observational studies. The multi-level analysis approach, encompassing these various data sources, provided a comprehensive understanding of the case. Such a holistic perspective allowed for the generation of insights that are valuable to both theoretical development and practical applications. A distinguishing feature of this study was the active participation of the researcher in the project, adopting the role of an active observer and immersed participant. This insider's perspective enriched the data by capturing not only what was explicitly stated but also the unspoken norms and subtleties of the context. It contributed to a deeper understanding of the case by offering a nuanced perspective that may not have been accessible through conventional research methods.

The study maintained a reflexive stance, evaluating its own perspectives and biases. Rigorous data analysis was conducted to ensure credibility and trustworthiness. The chapter's structure is designed to address research questions, incorporating literature review, stakeholder interviews, questionnaire feedback, and observations. This multifaceted approach ensures robust, contextual research outcomes that align with the holistic spirit of ethnographic research.

5.2 The BIM experience at ECDSWC on the CoESCoEM project

5.2.1 Introduction

This research has employed multiple data collection methods to investigate the implementation of Building Information Modeling (BIM) at ECDSWC. The study has used questionnaires to gather information about the participants' perceptions, opinions, and experiences with BIM. Interviews were conducted with key stakeholders to gain a more in-depth understanding of their views and insights about BIM implementation. The research has also reviewed project data, including design models, construction drawings, and diagrams, to identify the extent to which BIM has been used in projects. As an active participant in the project observations and deductions were also made during the design project timeline to analyze BIM implementation. Collectively, these methods have provided a comprehensive picture of BIM implementation at ECDSWC, enabling the identification of strengths, weaknesses, opportunities, and challenges related to the adoption of BIM in the organization.

5.2.2 Administrative

This section provides a detailed analysis of the implementation of BIM at ECDSWC. The data was gathered through a combination of interviews conducted with key management personnel, distribution of questionnaires, and thorough document reviews. These methods were chosen to ensure a comprehensive understanding of the BIM implementation process within the company.

The individuals interviewed for this study hold critical positions within ECDSWC and play instrumental roles in driving the successful adoption and integration of BIM into the company's operations. Their diverse range of responsibilities encompasses contract management and drafting, design approval, quality assurance, project management, and overall management of the organization. By engaging decision-makers across these key areas, we sought to capture a holistic perspective on the challenges, successes, and best practices related to BIM implementation at ECDSWC. The interviews conducted with these individuals provided valuable insights into their experiences, strategies, and perspectives regarding the implementation of BIM for the project. The questionnaire distribution further supplemented the interview findings, providing a broader understanding of their perceptions, decision making process, challenges and potential areas for improvement.

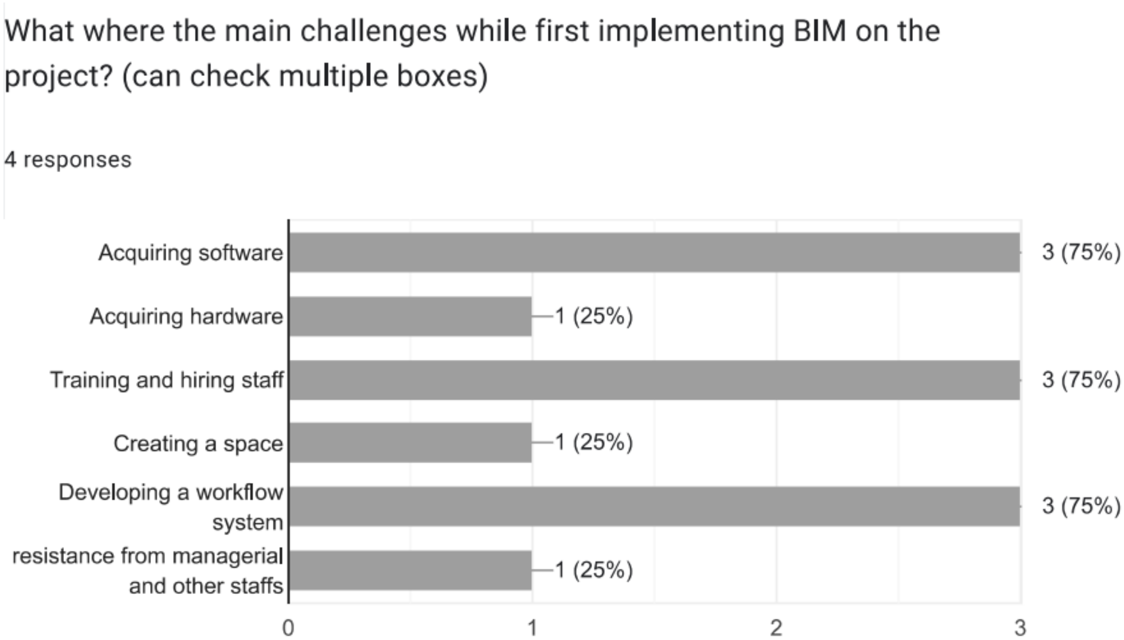

Figure 19 Data obtained from questionnaire

The management team has identified three key priorities: acquiring BIM software, training and hiring BIM-adequate staff, and developing an efficient workflow system. Based on these interviews, further interviews were conducted to get a detailed understanding of the topics and form an analysis.

Purchasing AEC software: One of the major challenges identified was the initial investment the BIM project required, specifically acquiring BIM software. The management has identified the purchase of the AEC collection from AUTODESK Software as a significant challenge in the implementation process. These software packages frequently cost a fortune and require a sizable upfront investment. As a result, getting such software proves to be a difficult task, hindering BIM's effective application. For the project, ECDSWC approached an AUTODESK value-added distributor called WorldsView based in East Africa, Kenya, to get details on pricing and the types of packages AUTODESK provides. The tables below show one year subscription-based tier:

Product Description	Quantity	Unit Suggested Retail Price (US Dollar)	Suggested Retail Price (US Dollar)
Architecture Engineering & Construction Collection IC Commercial New Single-user ELD 3-Year Subscription	20	$ 2,467.80	$ 49,356.00
BIM Collaborate Pro - 10 Subscription CLOUD Commercial New 3-Year Subscription	2	$ 6,258.60	$ 12,517.20
Build – 5000 CLOUD Commercial New Single-user ELD 3-Year Subscription	20	$ 658.80	$ 13,176.00
Takeoff CLOUD Commercial New Single-user 3- Year Subscription	20	$ 945.00	$ 18,900.00
Total			**$ 93,949.20**

Table 3 1-year Subscription Pricing form AUTODESK (source: www.autodesk.com)

Such costs were not previously accounted for by many consultants if the company decided to purchase a yearly subscription of only the AEC collection for 49,356 UDS, which roughly converts to 2,665,224.07 Ethiopian Birr (at the time of writing April 14,2023). So going forward, contract negotiations should take this into serious consideration and add the cost to the design fee. It is expected that it will increase the design fee but it is also important to note that the BIM process will ensure quality and reduce errors in turn will save the client money in the construction and lifecycle of the building.

Contractual issues: The conventional contracts used at ECDSWC were established before the initiation of BIM. As BIM is becoming one of the design workflows at the company, the inadequacies of these existing contracts have become visible. These are some of the main oversights observed regarding BIM implementation in the contract document for the CoESCoEM project.

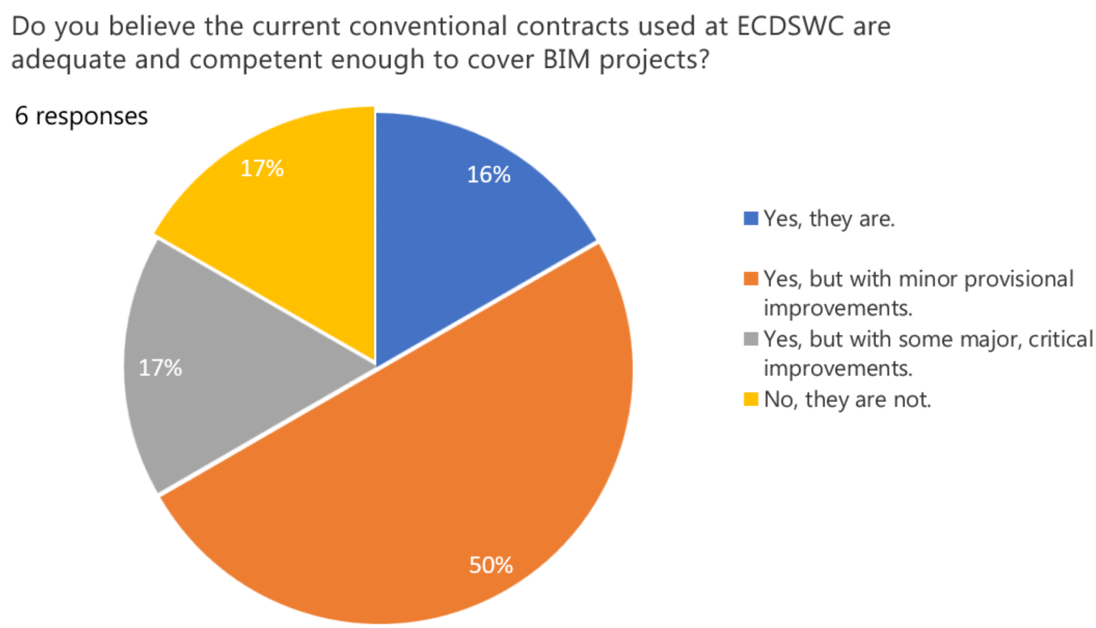

Figure 20 Adequacy of design contracts

- Not defining the scope of work for a BIM-based project clearly and not allocating adequate resources in a timely manner for BIM implementation resulted in delays, errors, and reduced quality.
- Not addressing BIM standards and protocols, which can led to interoperability, data exchange, and quality control issues.
- Not engaging knowledgeable BIM staff in contract negotiations and not addressing intellectual property rights which can led to disputes over ownership and use rights.
- Not addressing liability and risk management which can led to costly disputes and legal issues.

ECDSWC should avoid these mistakes in future projects by carefully considering the unique needs and requirements of BIM implementation and addressing them in the contract. Contractual agreements for BIM-based design projects should outline the scope of work, responsibility and liability, intellectual property rights, BIM standards and protocols, BIM software and tools, project schedule and timeline, and change management processes (Fathi, 2019). By addressing these issues upfront, the company can help to ensure a successful BIM implementation and avoid potential conflicts or misunderstandings. Additionally, it is possible to have a design fee that reflects the product of the BIM design process and contributes towards the ROI. This will ensure that the design team is properly compensated for their work and that the client understands the added value of using BIM.

BIM workflow development: Developing a BIM workflow is one of the major issues identified by the management. Although there is currently a design workflow for conventional projects, it is apparent that it is not directly applicable for BIM projects, according to the data gathered.

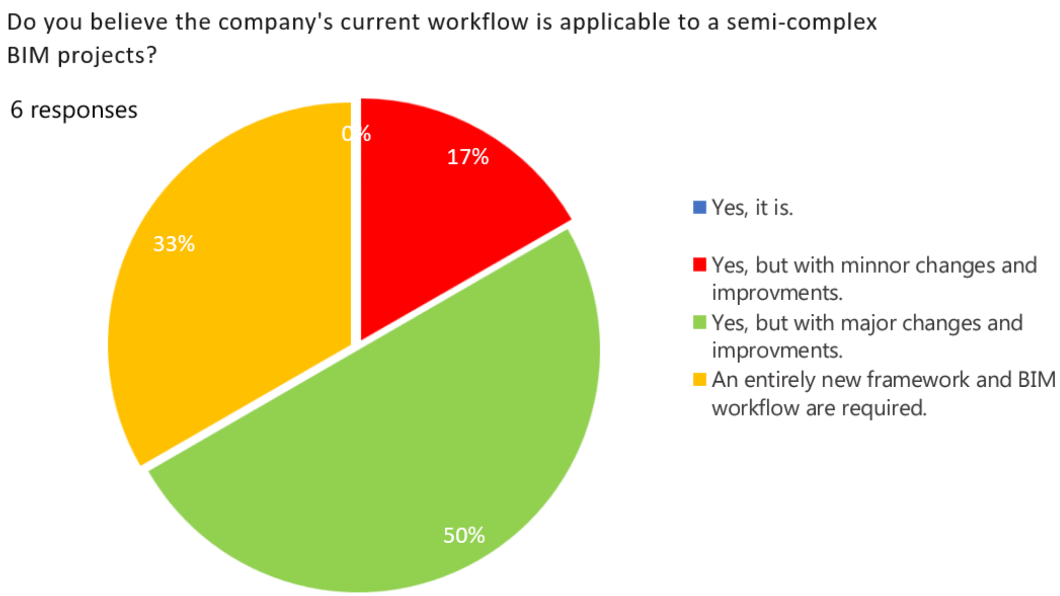

Figure 21 Company workflow

So, developing a customized BIM workflow that can function with the existing processes of the company was one major aspect that could enhance project delivery. Through the interviews, the interviewees noted what advantages a BIM workflow could bring to the company, such as improved collaboration, increased efficiency, and reduced errors. The management recognizes the importance of adopting a BIM workflow to stay competitive in the industry and meet the demands of clients. Therefore, it is crucial to invest time and resources in developing and implementing a customized BIM workflow that aligns with the company's existing processes. By doing so, the company can enhance project delivery, improve communication and coordination among team members, and ultimately achieve better project outcomes.

- Improved collaboration: BIM can help to improve collaboration between different members of the project team, such as architects, engineers, contractors, and owners. This is because BIM models can be shared and accessed by everyone involved in the project, which can help to ensure that everyone is on the same page and that there are no misunderstandings.

- Increased efficiency: BIM can help to increase the efficiency of the design and construction process. This is because BIM models can be used to automate many tasks, such as generating 2D drawings and schedules.
- Improved communication: BIM can help to improve communication with clients and stakeholders. This is because BIM models can be used to create realistic visualizations of the building, which can help clients to understand the design and make informed decisions. In the study project all other data produced using the BIM tools has no contractual framework in which the client can access or get the data produced. These include the BIM model, building performance simulations, construction simulations, clash detection reports, and design analysis.
- Improved decision-making: BIM models can be used to simulate different scenarios, which can help firms make better decisions about the design and construction of a building.
- Project delivery methods: Despite the use of BIM, the project was ultimately delivered in hardcopy format, which means that the final product was not delivered digitally. The reason for this was directly related to contractual obligations that were not conducive to digital delivery. In other words, the terms of the contract did not account for the project to be delivered in a digital format; all project deliverables were in hardcopy and PDF format, even though BIM was used during the design process.

Technically adept staff: One of the significant challenges mentioned in the interviews and observations was the need for personnel with higher-than-average BIM software knowledge and skills. The time needed to get a beginner team at ECDSWC up to speed with the software was also a concern, as it could potentially delay project timelines and increase costs. The team will require time and investments for more advanced training to become more proficient, with the BIM tools and workflow. It is important to consider the long-term benefits of investing in training for the team, as it will lead to more efficient and effective project delivery in the future.

Additionally, providing ongoing support and resources for continued learning can help the team stay up-to-date with new software updates and industry advancements.

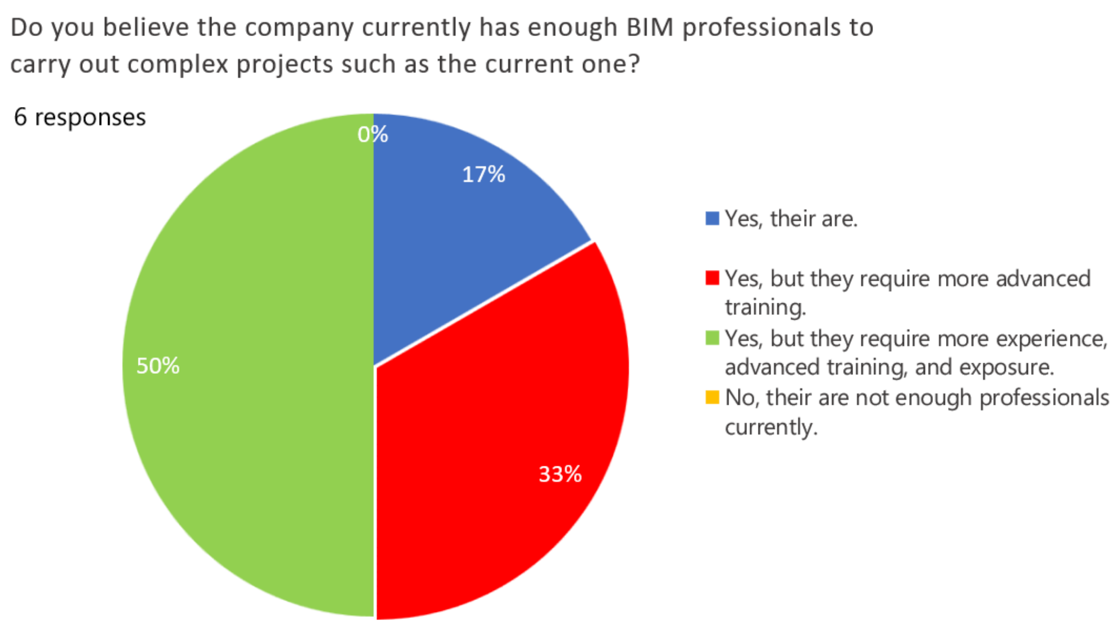

Figure 22 BIM staff cabablilies

Finally, clear project planning and efficient communication channels between all parties involved in the project can also pose a challenge. With these potential challenges, careful planning and communication are crucial to a successful BIM implementation. The paragraph emphasizes the need for the ECDSWC team to understand the challenges and devise strategies to overcome them to ensure successful BIM adoption.

5.5.4 BIM team

Participant observation, conversations, and questionnaires were used as qualitative research methods that involved the researcher immersing themselves as a participant in the environment being studied in order to gain a deeper understanding of complex relationships and human factors is the BIM design process. According to Schensul et al. (1999), it entails learning through exposure to and involvement in the day-to-day activities of participants in the research setting (Schensul, 1999).

By establishing relationships with the participants, the researcher can eventually detach from the environment and analyze the collected data. The definition of participant observation encompasses various data collection methods such as observation, natural conversations, interviews of different types, checklists, questionnaires, and other unobtrusive techniques (Schensul, 1999).

In the case study discussed here, participant observation was employed to immerse the researcher in the context of the site and enhance the development of research tools for both qualitative and quantitative data. The researcher from the BIM team conducted interviews, observations, questionnaires, and meetings throughout the project design lifecycle to gather insights on BIM implementation. These research methods allowed the researchers to gain valuable insights into the subject matter, understand the complex relationships at play, and extract meaningful analysis from the collected data. By assimilating into the studied environment, the researchers were able to enhance their understanding of the connections and implications of their findings. The figure below denotes how participant observation, conversations, and questionnaires were used in the case study.

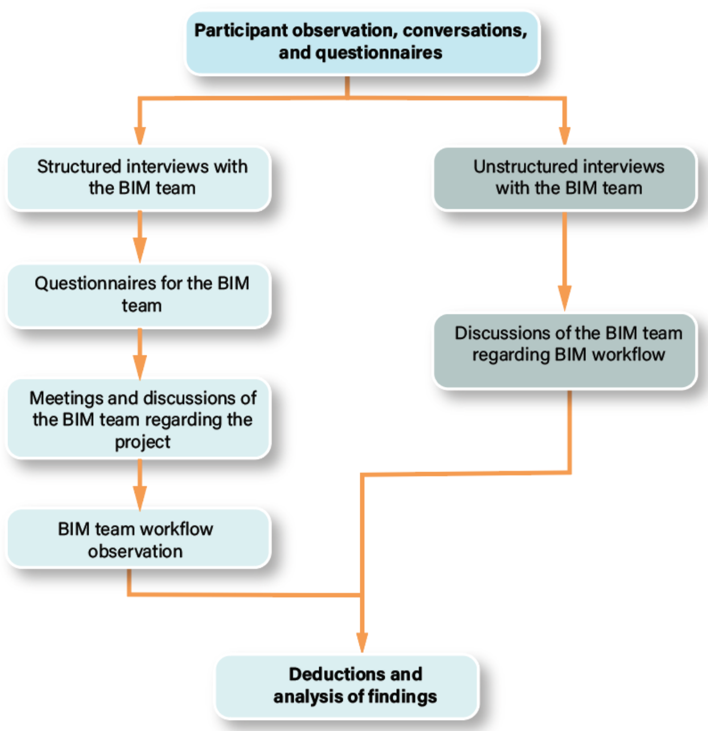

Figure 23 Data gathering method

Additional predesign preparations: Preparing or even buying premade Revit design templates for each discipline which optimized for the BIM design workflow. This working template will provide a reliable way to begin each new project file and ensure that it starts with the right collection of settings, features, and office standards. These templates are very crucial and contain important aspects listed below:

- Drawing standard
- Measurement standards
- Writing standards
- Discipline based worksets in Revit
- Formal collaboration methods/platforms
- BIM building components such as composite walls, curtain walls, slab composites, pipes, wires, fittings, rebar, ducts …
- BIM families (furniture and fixtures)

Market available objects or equivalent Revit families: When starting from scratch a BIM design team it is crucial that the team first prepare, search and organize Revit families which they are going to use in the coming project. Doing this while doing the design can be very distracting and time wasting. Also related to these online platforms where someone can get BIM objects are linked to a manufacturer, when a designer gets a BIM object from such websites the person is not sure about the availability of the equipment they chosen in the local market. This is why it is important to prepare a library of BIM objects with full specification and properties which have been modified so they are more similar to what is available in the local market.

Revit Add-ins: There are several free and paid for add-ins that aid the workflow for each discipline. Some of these tools offer a quality-of-life upgrade and make otherwise repetitive tasks easy. At the beginning these may seem extravagant but these tools will become more and more a necessity as the BIM implementation expands and the scope of work becomes more complex.

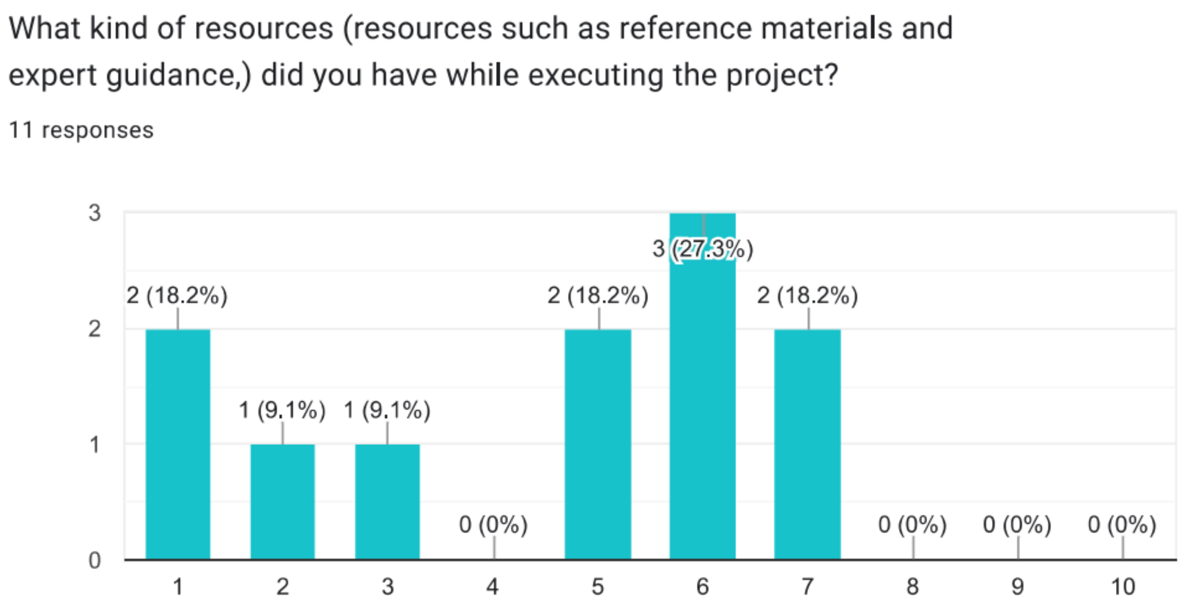

Figure 24 Resources for the BIM team

Dynamo: Autodesk Revit has a visual programming add-in called Dynamo. Building information modelling (BIM) processes can be customized and automated with the help of Dynamo's open-source graphical programming. There are numerous Dynamo scripts that automate repetitive and arduous tasks. These scripts can clear a section of warnings in any given model in just a few seconds. The BIM team lacks deep understanding of such node-based design systems. The BIM team can create these scripts with enough time and resources, which will simplify many tasks. These scripts can also be reused repeatedly in numerous upcoming projects.

A structured collaboration and workflow systems: A standardized office work flow system based on ISO 19650 (is an international standard for managing information over the whole life cycle of a built asset using building information modelling (BIM)) standard needs to be established for an optimal workflow. With out an organized collaboration system many aspects of the design may have errors, repetition and waste of time.

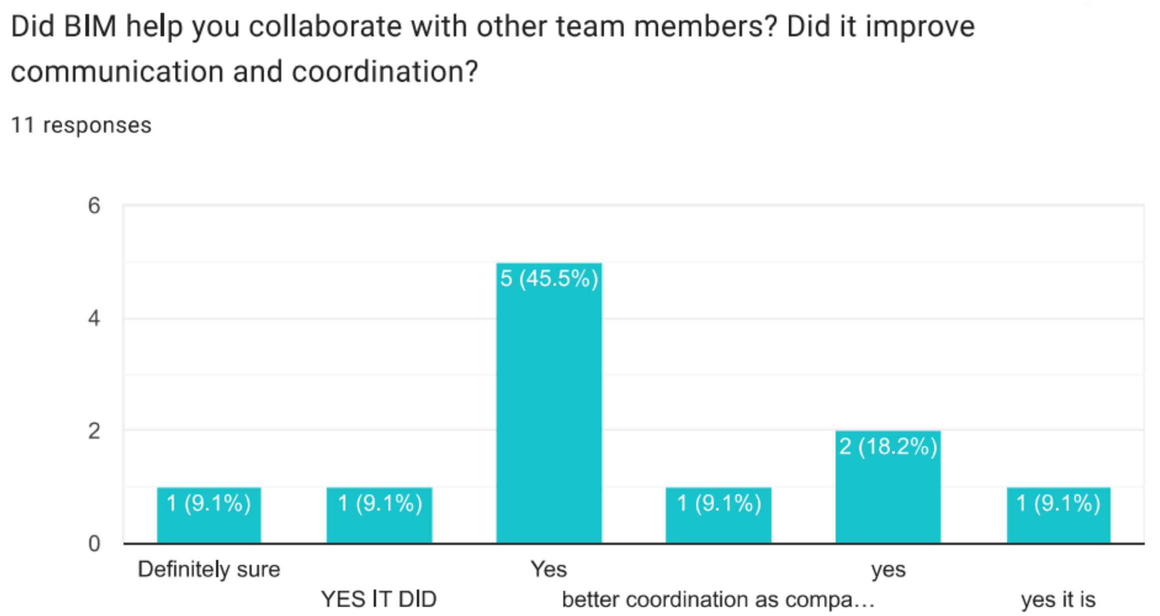

Figure 25 Data collected regarding collaboration

Milestone setting: Each team member, with respect to their profession, needs to be able to refer to a task matrix and identify their task at each milestone or phase of the project. In addition, milestones need to be set beyond the arbitrary allocation of LOD to each model This ensures that each team member is aware of their responsibilities and can work towards achieving the project goals effectively. Setting clear milestones will also help in tracking the progress of the project and making necessary adjustments to ensure timely completion. A workflow chart should be prepared and posted at the office for easy reference.

Time schedule: the project had a rushed time frame due to so much time being not utilized at the beginning of the project. This was apparent for the BIM team, having less than a month to design a building with such scale was very frustrating, stressful and challenging. The arduous project timeline further contributed to their being many errors and significant omissions, such as clash detection, a structured work plan, and sufficient BIM resources. As a result, the project team had to spend most of the time trying to produce design documents and deliverables for a deadline.

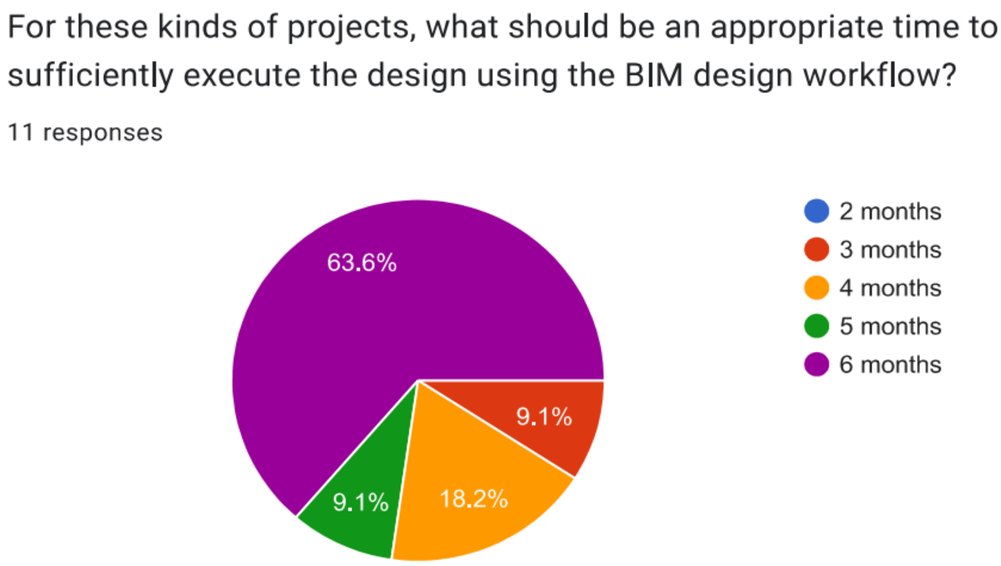

Figure 26 Data collected regarding appropriate time schedule

Individual level Task allocation: Each BIM milestone should be elaborated on, and each task should be detailed and assigned to a designated person. This will enable us to track the project's progress further and identify weak points and difficult tasks. Furthermore, regular communication and collaboration among team members are crucial to ensuring that everyone is on the same page and working towards the same goals. This will help to avoid delays and ensure that the project is completed on time and within budget.

Technical and practical excursions know how: A technically adept, highly competent person is needed to guide each person with their task This person should have practical excursions know-how and be able to provide guidance and support to ensure that each task is completed successfully. Additionally, they should be able to troubleshoot any issues that may arise during the process.

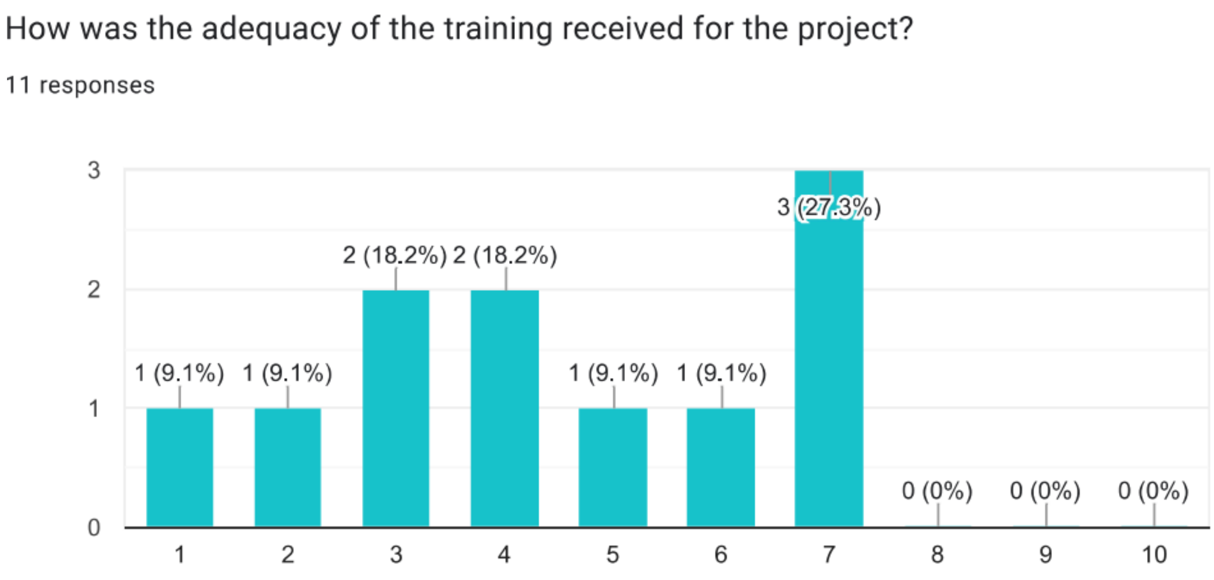

Figure 27 BIM Training adequacy

Technical expert leadership: For the success of any project, a strong, confident, knowledgeable, and technical adept point person is key. Without such a technically adept leader, the project may face significant challenges and may not be completed efficiently or effectively. The leader's ability to guide and motivate the team toward a common goal is crucial for the project's success.

The most significant change that the team faced when implementing BIM technology was intensively using a shared building model as the basis of all work processes and for collaboration during the design phases. This is the first time for the team, and due to the urgency of the project, the team has encountered technical hurdles, which have been documented, analyzed, and resolved in order to improve the implementation process for future projects. All the technical issues and the team's solutions have been documented below.

Software: Using a cracked (not authentic) copy of Autodesk Revit 2020 to carry out the project can result in a variety of unforeseen technical problems. The team wasn't able to get 10 licensed copies of the Autodesk AEC collection until after November 24th, 2022. Using unlicensed software is not recommended because the BIM process has many built-in redundancies and the cracked versions lack online functionality. The team was glad to have the licensed software at last because it would help them work more quickly and with more assurance about the precision of their work. They would be able to work with other teams and stakeholders more effectively if they had access to online capabilities.

5.3 Transitioning form the conventional workflow into a BIM workflow

In this section, two projects were taken to compare the conventional and BIM workflows at ECDSWC from the CoESCoEM project in order to identify the challenges faced by ECDSWC when transitioning from the conventional design workflow to the BIM workflow.

The CoESCoEM project encompasses a large-scale campus with multiple buildings, and for this particular investigation, the focus was on the phase one projects. Among these projects, two different design workflows were examined, with one of them utilizing the conventional design method, while the second project was developed using the BIM design method. It is worth noting that all the projects under consideration were initially intended to utilize BIM. However, due to constraints such as limited resources in terms of personnel, time, hardware, and software, only one of the phases one projects, namely the larger administration building, was ultimately designed using BIM. This comparative analysis aims to shed light on the differences, advantages, and potential drawbacks of using BIM over conventional workflows in the context of a complex project like CoESCoEM. By examining these three distinct design projects, the study seeks to provide valuable insights into the efficiency and effectiveness of BIM adoption in large-scale construction endeavors.

5.3.1 The conventional project workflow at ECDSWC

The analysis focuses on the conventional workflow at ECDSWC, specifically examining the teaching center (classrooms building) within the CoESCoEM project as a case study. While this building is relatively less complex in terms of design program, requirements, and size compared to other structures on the campus, it was chosen to undergo the conventional design workflow. The design process for the teaching center spanned four weeks, during which the architectural, structural, and MEP engineering aspects were addressed. The first two weeks were dedicated to the architectural design, while the subsequent 8 days were allocated for the completion of the structural and MEP engineering work. The final week of the design process was utilized for quantity surveying and the preparation of other essential documentation required for submission.

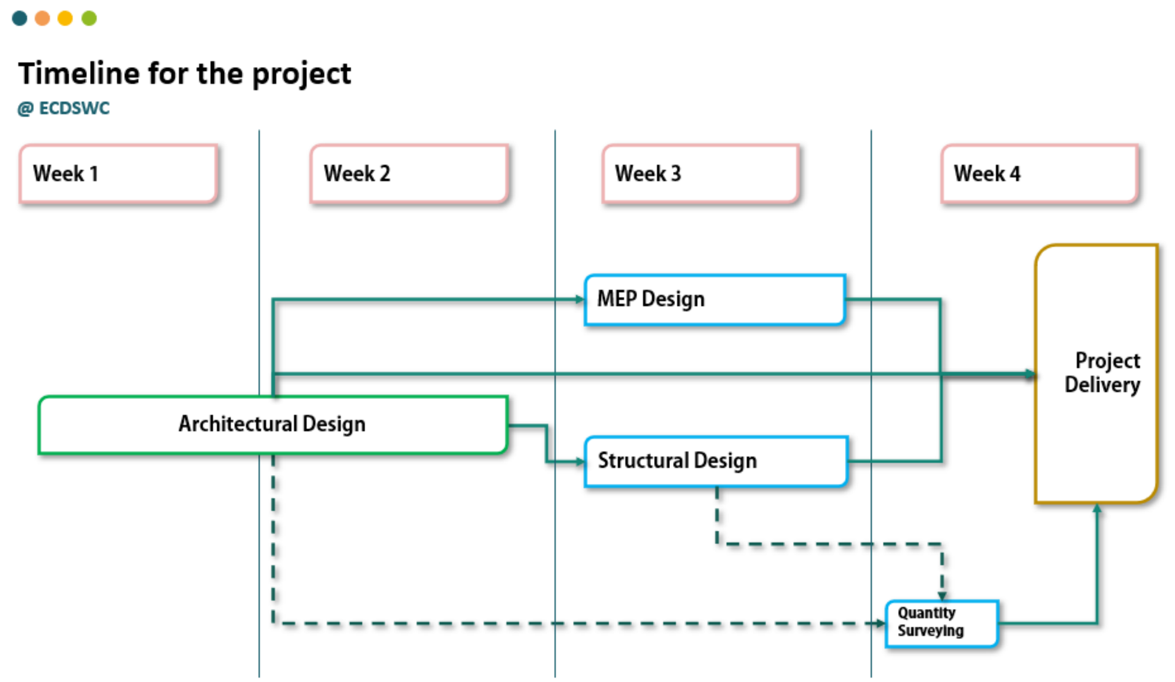

Figure 28 Simplified project timeline

The conventional workflow is typically structured as a linear process, where each stage of the design must be accomplished before moving on to the subsequent phase. In this context, the engineering team's initiation of work is contingent on the architectural design team completing their tasks, preferably up to the preliminary design stage. Consequently, the architectural design reaches a more advanced level of maturity before any engineering activities can commence. Due to this rigid sequence, there is limited room for design iterations and exchanges of ideas between various disciplines. Consequently, any modifications or revisions to the architectural design after the engineering work has already commenced can pose significant challenges and complexities.

The lack of flexibility in this linear workflow can potentially give rise to conflicts and coordination issues among the different design teams. As the architectural and engineering teams operate in a somewhat disconnected manner, any alterations to the architectural aspects may necessitate backtracking or adjustments in the engineering domain, causing delays and inefficiencies. Furthermore, this approach restricts the exploration of alternative design possibilities and hinder the optimization of the final product.

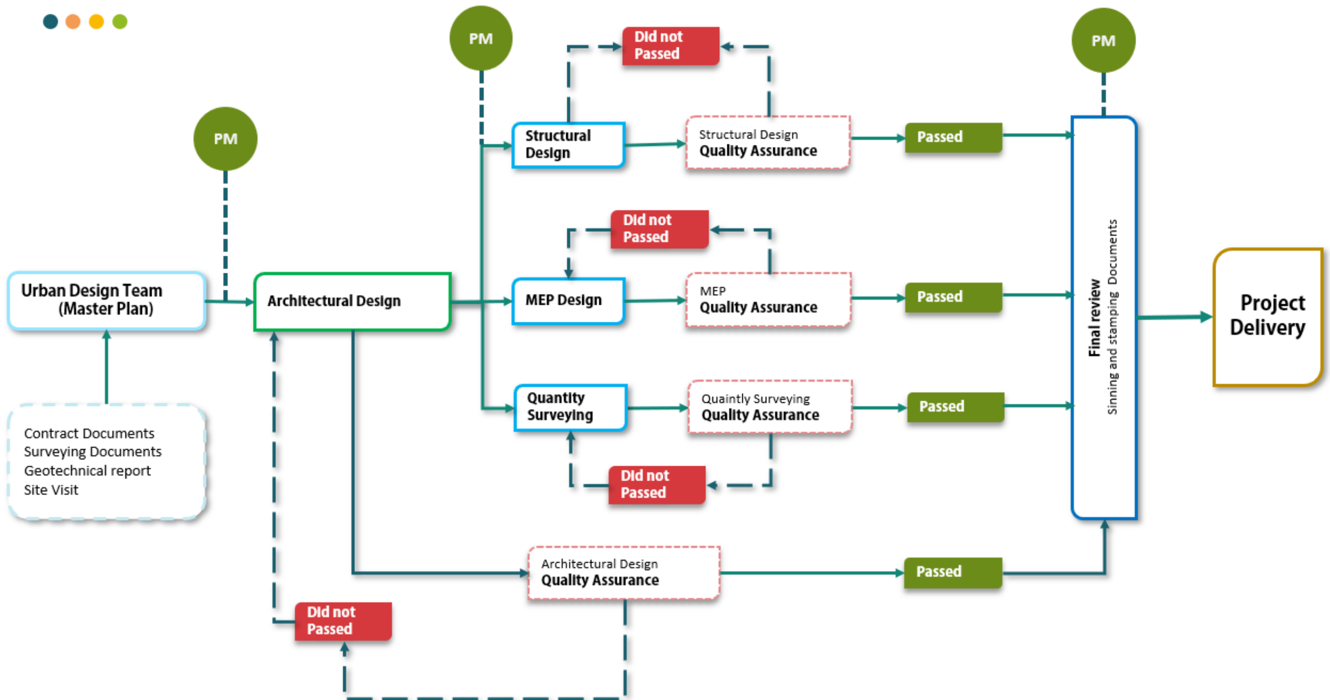

Figure 29 Abstract Project workflow at ECDSWC

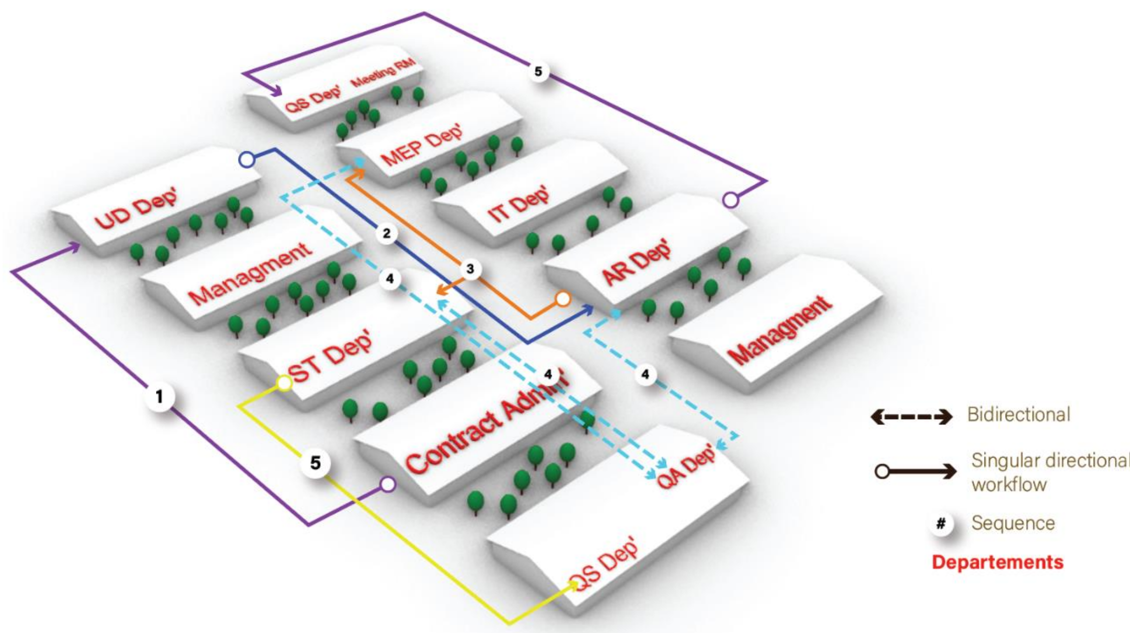

Figure 30 Spatial Project workflow at ECDSWC

The diagrams above show the spatial abstract workflow at ECDSWC conventional workflow model. In the conventional model, the disciples are physically located in different spaces, representing various architectural, urban & engineering departments. The flow of information is very linear, with each disciple (department) receiving a set of drawings from the architecture department and working on their respective parts separately.

The workflow showed a significant lack of reiteration of design with the interdisciplinary departments. Such a system exhibited minimum collaboration and communication structured around it, with the project manager (PM) often being the only link between the departments.

Consequently, this system was prone to mistakes and experienced questions and inquiries from contractors during the construction stages. The limited collaboration between departments led to misunderstandings, inconsistencies, and challenges in executing the project. Integrating a more collaborative approach with enhanced communication among the disciples and departments would have significantly mitigated these issues and fostered a more streamlined and successful project development process.

In this model, the spatial dispersion of disciples across different locations presented both challenges and opportunities. On one hand, physical separation hindered face-to-face interactions, making communication and collaboration more difficult. On the other hand, it opened up possibilities for leveraging digital tools and virtual platforms to bridge the gap and promote efficient information sharing.

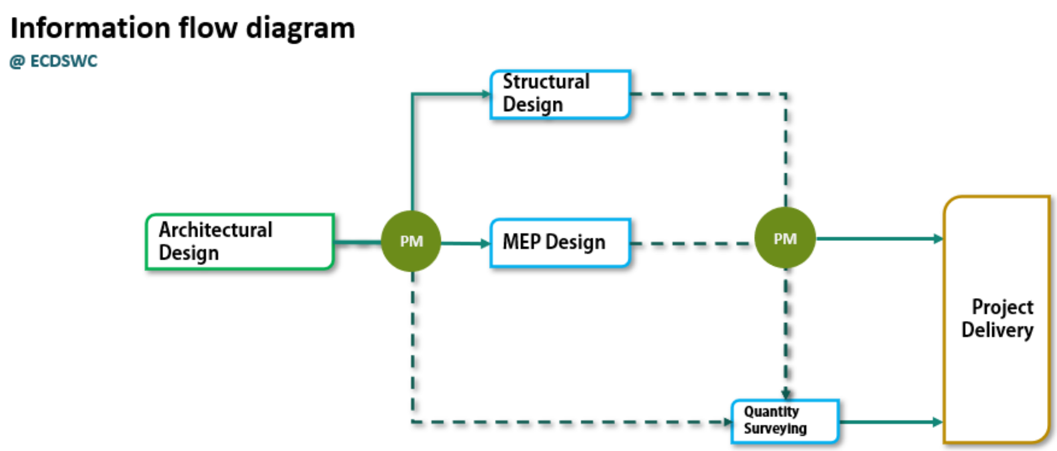

Figure 31 Information flow diagram

The linear flow of information from the architecture department to the engineering disciplines streamlined the initial stages of the project. However, it also resulted in a siloed approach, where each department focused solely on its part without a comprehensive view of the overall project. Implementing periodic design reviews and interdepartmental meetings would have fostered a more holistic understanding of the project's intricacies and facilitated the exchange of valuable insights among team members.

The lack of reiteration of design between the interdisciplinary departments may have stemmed from a rigid and hierarchical project structure. Introducing iterative feedback loops could have encouraged frequent exchanges of ideas and feedback, leading to better refinement of the design. This iterative process would not only have enhanced the quality of the final output but also fostered a culture of continuous improvement within the organization.

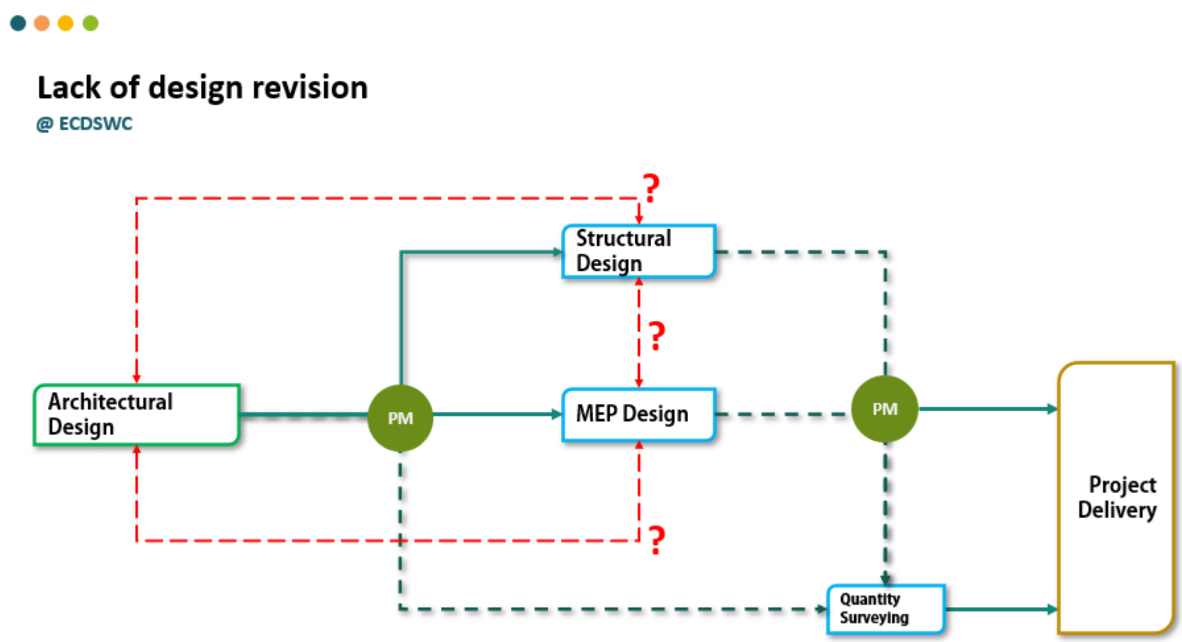

Figure 32 Workflow shortcomings

The minimal collaboration and communication structured around the disciplines were detrimental to produce an efficient design. Encouraging cross-functional teamwork and interdisciplinary brainstorming sessions could have spurred new ideas and solutions that were not possible in relative isolation. It is important to acknowledge that is not the case in every project, the collaborative nature of any project depends on the individual's willingness to collaborate with each other. this puts different projects have different out comes based on the level of collaboration and cooperation among team members. In projects where individuals from different disciplines actively engage and share their expertise, the final outcome is more often has less errors and collisions. On the other hand, if team members are resistant to collaboration and prefer to work in isolation, the project may suffer from missed opportunities and lack of diverse perspectives.

While the project manager played a crucial role in coordinating various aspects of the project, a heavy reliance on a single point of contact could led to bottlenecks and potential delays. Empowering team members to take ownership and communicate directly with relevant design departments could have expedited decision-making and promoted a sense of shared responsibility.

Due to the urgency of the project, it is exposed to mistakes and future inquiries from contractors during the construction stages. Despite the clear coordination and collaboration issues this design process had, it was ultimately delivered on time with all the required documents. It should be said that the design of the building is subject to change and revision.

While direct communication between the design departments was very limited, it is important to note that the design of the building was completed on time and the required documents were delivered, suggesting that with better and more organized coordination and collaboration, the conference method may still be effective. This will depend on the type of project and the team that is involved in the design process.

5.3.2 The BIM team’s workflow for the CoESCoEM project

The implementation of BIM aimed to transform the previous project development model into a more integrated, collaborative, and iterative system, leading to increased efficiency, innovation, and overall success. Emphasizing effective communication, fostering cross-disciplinary interactions, and embracing continuous design improvements were key factors that can pave the way for a more streamlined and resilient approach to design projects. To achieve these goals, several major steps were taken, starting with meticulous preparations and spanning throughout the various design phases. This section will highlight and analyze the key aspects of the BIM design implementation process. By integrating these strategies into the project development, it was anticipated that BIM would enable greater adaptability and responsiveness, creating a more dynamic and efficient design environment.

Predesign preparations: The preparation for the CoESCoEM project involved careful planning and organization to ensure that the project runs smoothly and efficiently. Key steps to consider in the predesign preparation phase include determining project goals, developing a BIM execution plan (BEP), assembling the project team, setting up project protocols, defining model requirements, developing a modeling strategy, setting up BIM software and hardware, and ensuring that all necessary BIM software and hardware are in place and configured for optimal performance. These steps can help ensure a successful BIM project that meets the needs of all stakeholders and delivers the desired outcomes.

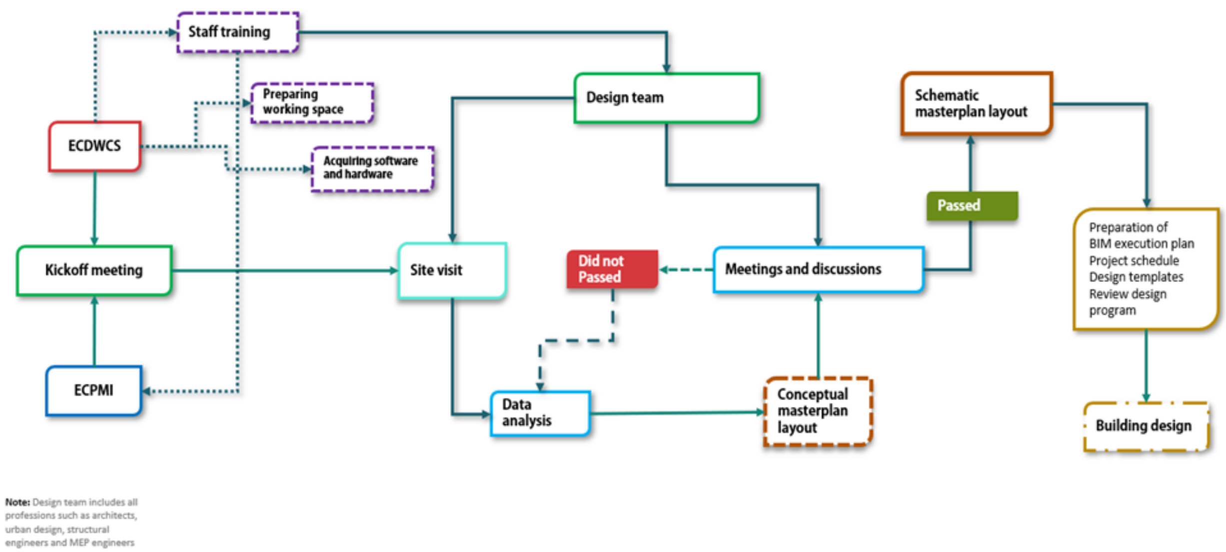

Figure 33 Predesign strategies

Staff Training: The Construction Management Institute (CMI) conducted a 20-day BIM training program for a team of 12 professionals to design the administration building for the CoESCoEM project. The training was based on the Autodesk BIM training manual and covered Autodesk Revit and Autodesk Navisworks. The course covered BIM workflow, project collaboration, and data management. The team consisted of four architects, two project managers, three structural engineers, and three MEP engineers. CMI is an Autodesk Authorized Training Center, allowing students, educators, consumers, industry professionals, and businesses to discover innovative ways to design and create products of the future. The training is provided by professional staff of Autodesk Certified Instructors, ensuring that the training meets industry standards and is of high quality.

Acquiring software: The ECDSWC team made a crucial decision to select an appropriate software package for their BIM project. Considering factors like training resources, staff familiarity, collaborative features, reliability, industry-standard software, and client demand. After careful evaluation, the AutoDesk suite of BIM tools and platforms, including Revit, Navisworks, and AutoCAD was selected. This software suite met the team's requirements and provided a robust set of features. Although obtaining genuine copies of the software was initially challenging, CMI recognized the importance of the software and provided 10 copies to expedite the design. This highlights the importance of software selection and collaboration between stakeholders for project success.

Acquiring hardware: The CoESCoEM project required efficient handling of complex BIM models for timely and accurate completion. ECDSWC prioritized the acquisition of high-quality hardware from a reputable company, providing 12 Dell OptiPlex 7090 computers with Intel® Core™ i7-12700HL 10-core processors, NVIDIA RTX A4000 graphics card, and 1TB SSD. These computers were crucial for processing large and complex BIM models without compromising accuracy or speed. Collaborative data management was essential for smooth information flow among team members. A 5TB storage space was allocated on the company's server, enabling efficient project execution and reducing data loss risks. ECDSWC's strategic decision in investing in high-quality hardware enabled the BIM team to work efficiently and accurately while keeping up with the project's increasing complexity.

Design stages: The design stage begins with gathering a BIM design team in a "big room" office space. This approach maximizes the close coordination BIM provides, improving project design quality and shortening project durations. This eliminates the need for meetings and emails, promoting team communication and real-time problem-solving. Working in a physical space allows for faster decision-making and immediate feedback from all team members. This approach is an efficient way to enhance project design quality and reduce project (a collocated and collaborative work environment).

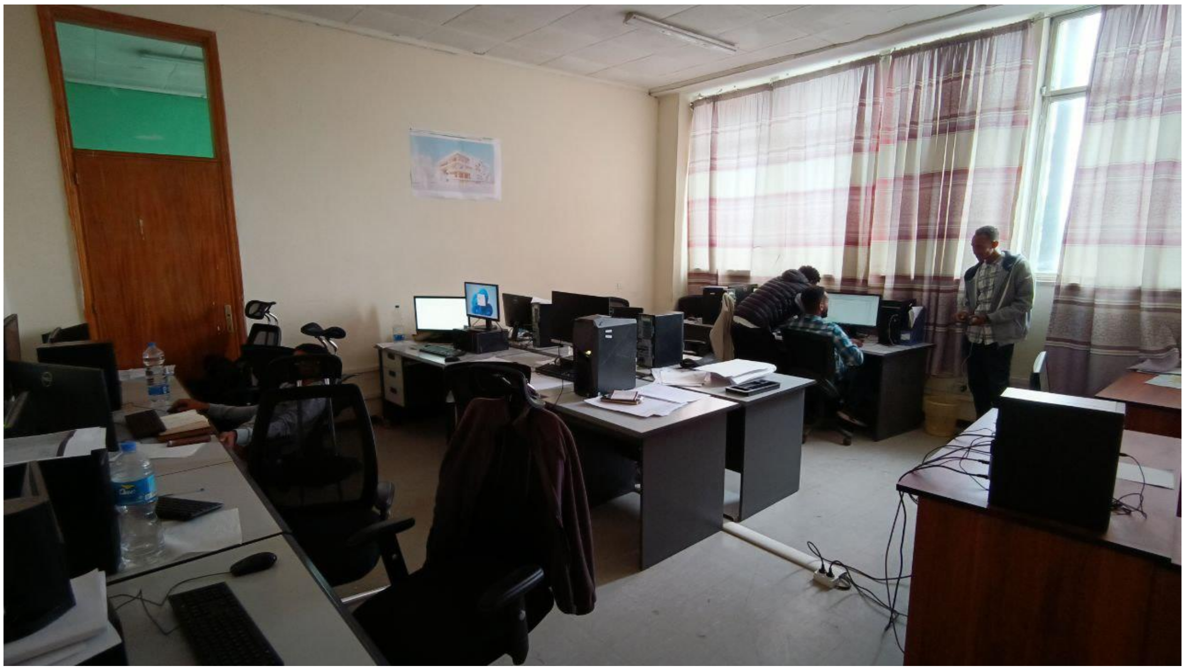

Figure 34 BIM teams working space

Furthermore, the physical co-location of team members within this 'big room' office space affords a tangible advantage: expedited decision-making. With all design teams present, decisions can be made promptly, and feedback can be gleaned instantaneously from each member of the design team. This instant feedback loop enhances the project's agility and adaptability, resulting in a more refined and efficient design process.

This choice of co-locating hinges on several factors. Firstly, it facilitates a highly productive atmosphere for effective communication and knowledge sharing among team members. The proximity of team members promotes spontaneous discussions and fosters a sense of unity, resulting in an exchange of insights that significantly enriches the design process.

Secondly, the viability of a collocated approach depends on the method of data sharing adopted. In instances where localized network solutions are preferred, physical proximity becomes essential as these systems often necessitate shared access within the confines of a specific workspace.

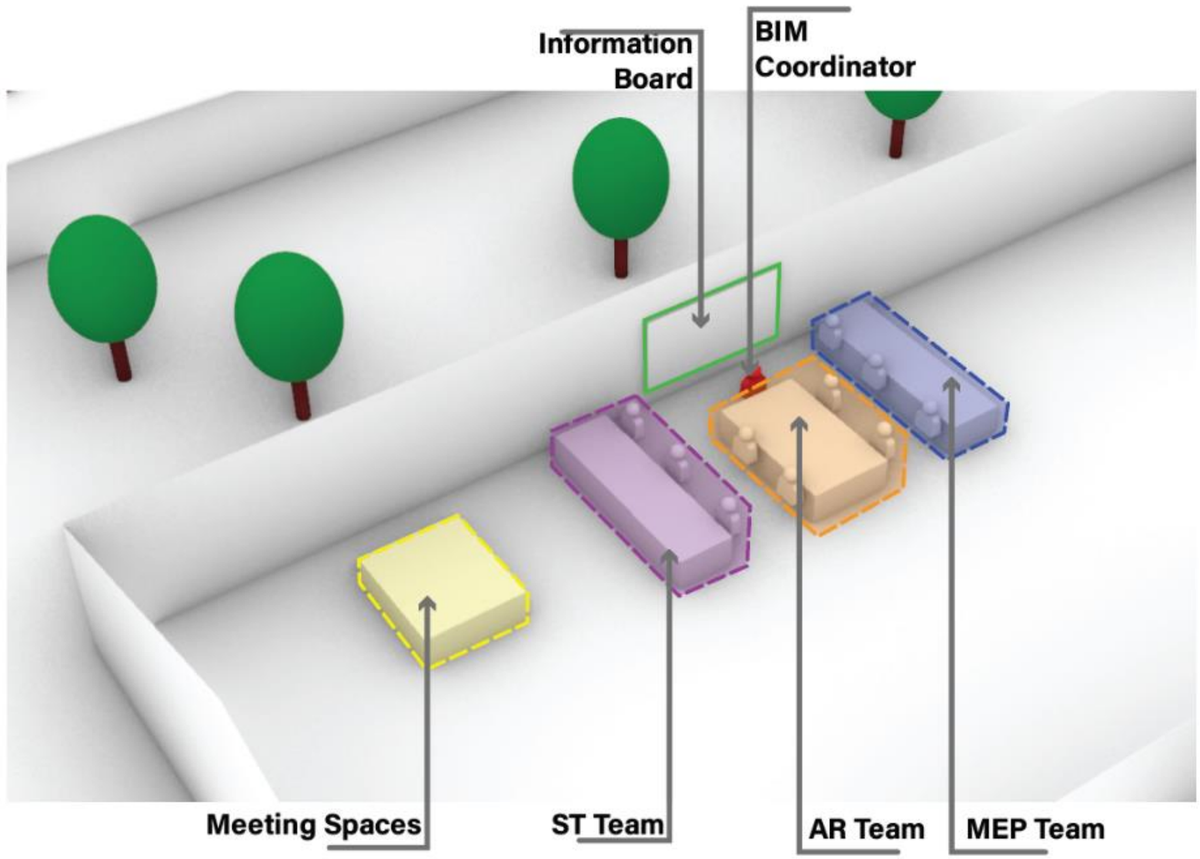

Figure 35 BIM teams ideal working space

The utilization of BIM technology does not strictly necessitate physical collocation. There are alternative options, notably cloud-based systems, which permit team members to contribute from various locations, irrespective of geographical distances. However, for a team that is relatively new to the intricacies of BIM and collaborative design, the 'big room' environment is invaluable.

Common data environment: The common data environment (CDE) is a collaborative platform that enables project team members to access, share, and manage project data in a single location. It serves as a digital hub for all project data, including design files, construction schedules, cost estimates, and other documents. The CDE improves collaboration and communication among team members, ensuring access to the most up-to-date information. It streamlines project workflows and reduces errors and inconsistencies that may occur when data is stored in multiple locations.

The current CDE uses mainly three folders: Archived, Shared, and Work in Progress. Archived stores outdated or outdated project data, while Shared stores shared data, published data, and Work in Progress data. These folders help keep project data organized, easily accessible, and properly managed throughout the project lifecycle. By utilizing these folders, the CDE ensures proper management and prevents errors and inconsistencies that can occur when data is stored in multiple locations.

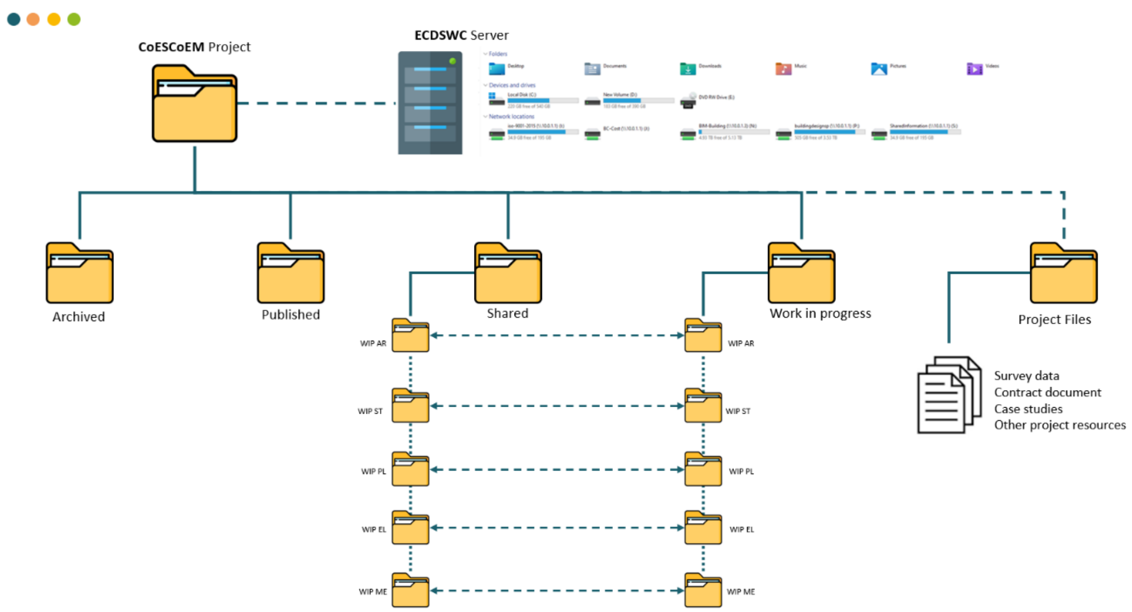

Figure 36 LAN based common data environment

Design workflow: Due to time constraints, the team had to forgo a dedicated BIM design workflow and opted for a slightly modified conventional approach in their design project. The modifications aimed to promote synchronized collaboration and information sharing across disciplines. The main advantage expected from BIM implementation was a seamless information exchange system. However, the improvised workflow might not have fully harnessed BIM's potential benefits. Despite this, the team managed to make progress. In future projects, allocating time for a well-structured BIM design process can lead to enhanced efficiency, minimized errors, and improved project outcomes. Properly integrating BIM technology can facilitate real-time updates and foster a more cohesive design vision, creating a more collaborative and successful project environment.

There was no organized or structured information flow system. As the team was a novice in regards to the BIM design process, they struggled to establish a design workflow system with no experience. Without a proper information flow system, important updates and changes would often get lost or delayed, leading to confusion and errors in the design process. It became evident that implementing a structured and organized system was crucial for the team's success in completing the BIM design project.

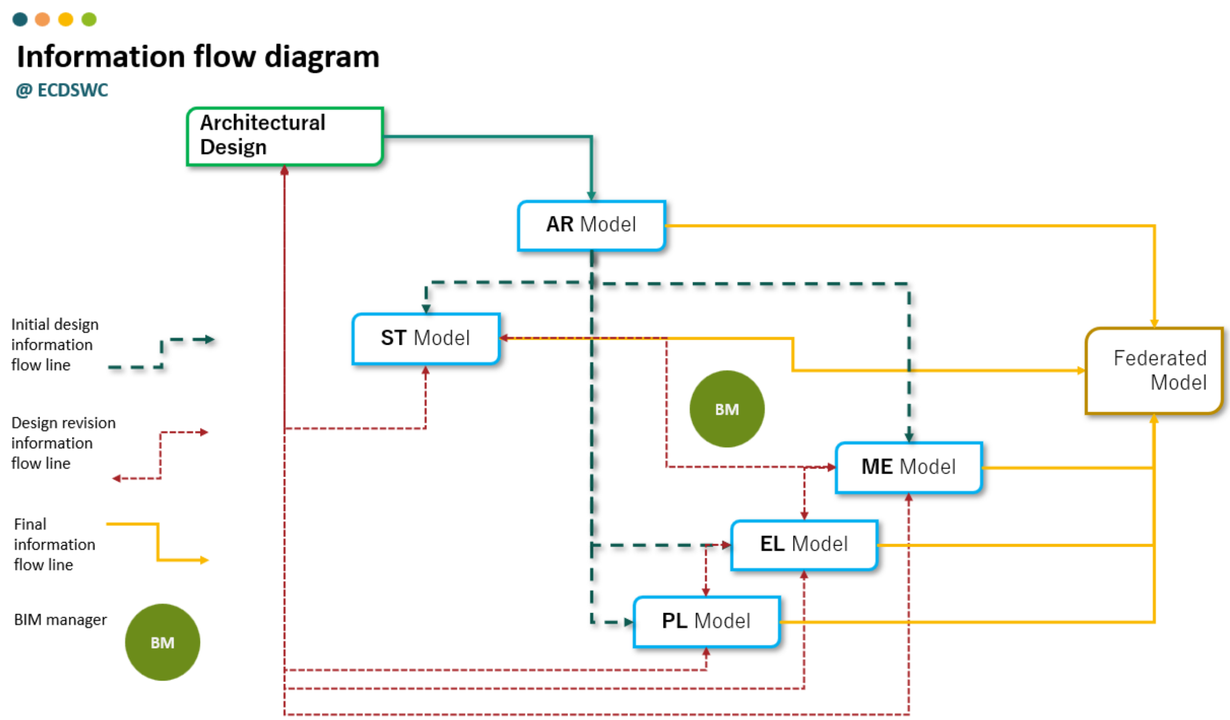

Figure 37 Simplified information flow

The diagram above was created based on observations of the information flow and work patterns of the team. Due to the tight time frame of the project, the team was not able to fully implement a proper BIM design workflow system, but they did make some changes to improve communication and information sharing. The team decided to hold regular meetings to discuss updates and changes, ensuring that everyone was on the same page. They also implemented a centralized document management system, where all project documents and drawings were stored and easily accessible to all team members. While these changes were not a complete solution, they did help to reduce confusion and errors in the design process, ultimately contributing to the completion of the BIM design project.

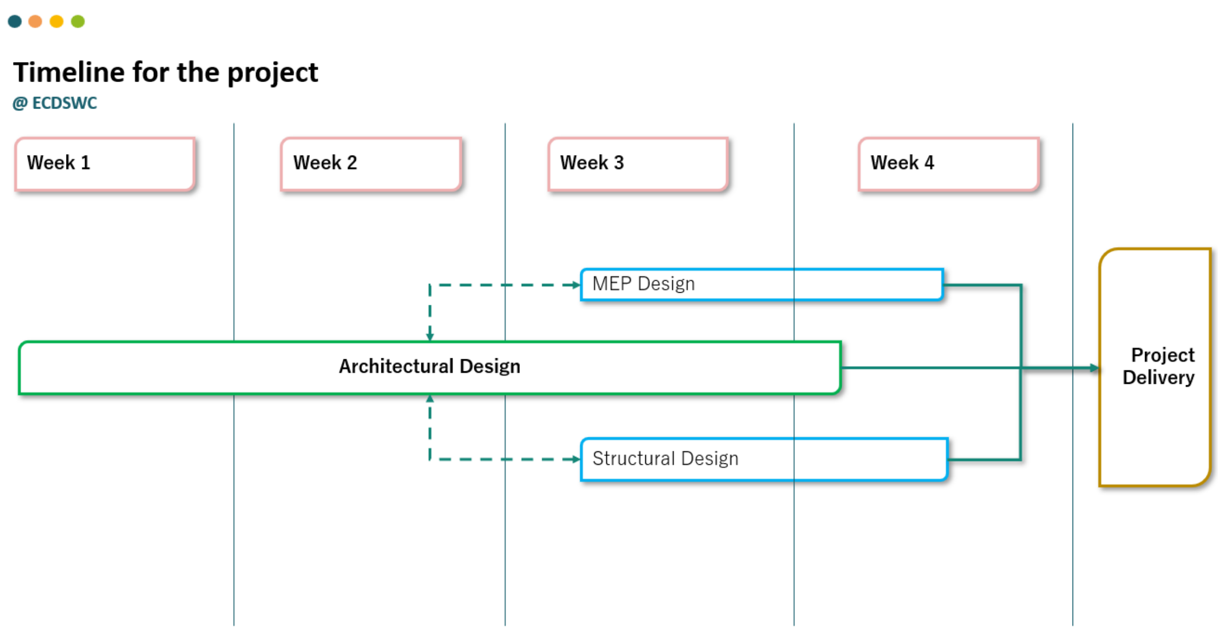

Figure 38 Project timeline

In the BIM model, the architectural design was being worked on at the same time as the structural and MEP design workflows. The teams were able to work in parallel, which allowed for design iterations and changes to be communicated really easily. This integration of design disciplines in the BIM model significantly improved collaboration and coordination among the teams. Any modifications made to the architectural design automatically updated the structural and MEP aspects, ensuring that all elements remained synchronized.

This streamlined workflow is aimed at saving time and minimizing errors on the grand scale of the project, but the design phase needs more time to carefully look at each design detail, conduct analysis, and make design revisions, which inevitably will take more time compared to the conventional method. The 4-week period depicted in the above diagram is not an adequate amount of time to implement BIM to a reasonable extent, and the advantages of the BIM process may not be fully realized within such a short timeframe. It is crucial for the design team to have ample time to fully understand and utilize the capabilities of BIM, ensuring that all design elements are properly integrated and coordinated. Rushing the implementation of BIM could lead to potential errors or oversights, ultimately hindering the project's overall success. Therefore, it is advisable to allocate a longer timeframe for the design phase to fully harness the benefits of

As indicated, due to the very short time frame, there were several issues in the design phase of the project. Most are directly corralled with limited time allocation, which causes serious technical issues. There were also some critical tasks that could not be completed because of the time limit. Some aspects of the design were not thoroughly analyzed or considered, resulting in errors or omissions that affected the project's, further compounding the issues faced. Allocating a longer timeframe for the design phase would have allowed for more thorough planning and problem-solving, ultimately leading to a more successful outcome for the project.

Clash detection: As of April 18, 2023, only initial clash detection has been performed on the CoESCoEM administration building through Revit links. However, it has been noted that Navisworks is the best compatible software for clash detection and revisions, and there is an intention to perform these tasks using that software. Unfortunately, due to time constraints and the need to rush the building design, a comprehensive clash detection and corresponding design revision could not be completed within the 26-day timeframe. This means that there is still more work to be done to ensure that the design of the building is structurally sound and meets all requirements.

Revit warnings: These warnings can range from simple notifications about minor issues to more critical errors that can affect the accuracy and integrity of the model. Clearing warnings is an essential step in the BIM workflow, as it ensures that the model is free from errors and can be used effectively for tasks such as clash detection, quantity takeoff, and construction documentation. There are several reasons why Revit warnings may occur. One common cause is due to the complexity of the model or the level of detail included. Other factors that can contribute to warnings include inconsistent parameters or properties, incorrect geometry, or incomplete elements. Rushed schedules and incomplete or inaccurate project data can also lead to warnings, as was the case with the ECDSWC project mentioned earlier.

During the project, the BIM team at ECDSWC encountered a significant challenge in the form of numerous warnings that needed to be cleared from each model. The team faced hundreds, and in some cases, thousands of errors, making it difficult to perform effective clash detection later on. The models had been created with speed in mind due to the rushed schedule, leading to an excessive number of warnings.

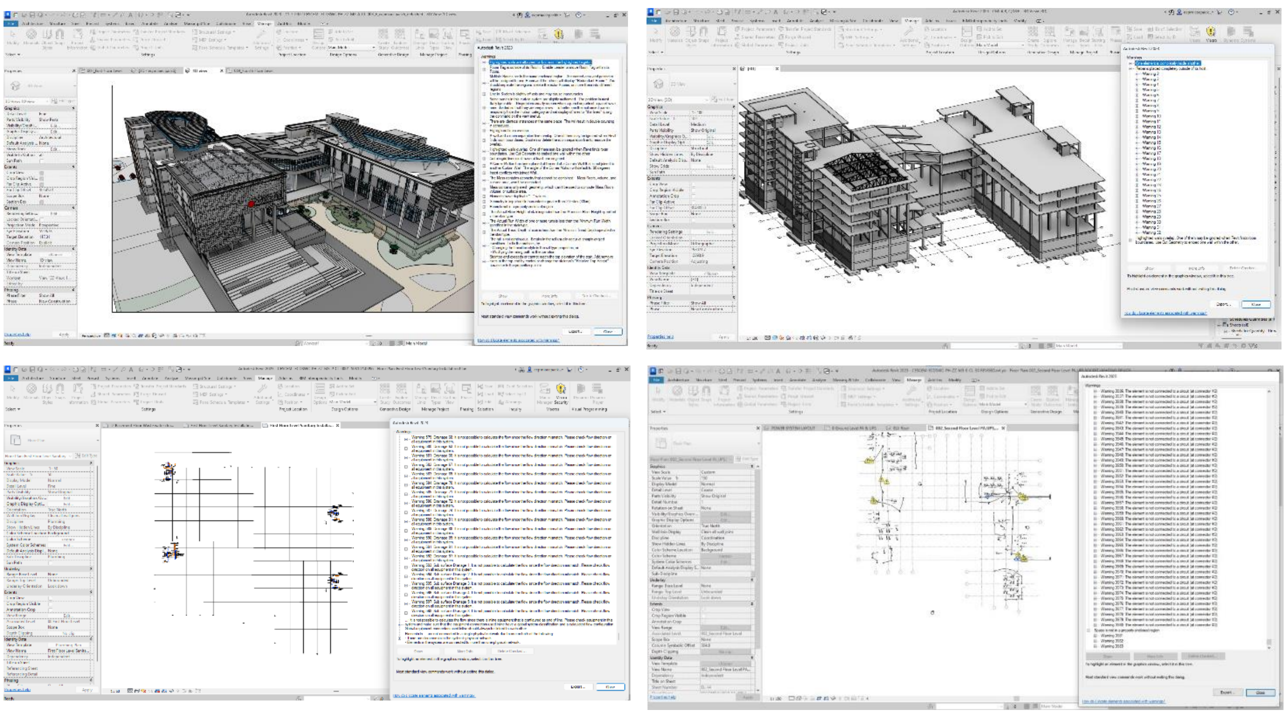

Figure 39 Revit warnings observed

Technical issues and solutions: These are some of the main technical issues observed during the BIM design workflow. The issues encountered have been documented along with their cause and solution to ensure future reference and to assist in troubleshooting. Some of the common technical issues include software crashes, file compatibility issues, and data corruption. Software crashes can be caused by insufficient system resources or bugs in the software itself.

- **Issue 0:** Model authorship and ownership of model elements in a central model
    - **Solution:** Everyone participating in the project should sign in to an Autodesk account, regardless of the status of the software (cracked or genuine).
- **Issues 1:** model is missing many elements and cannot be solved. Date 10/9/2022

- **Cause** loading families into the project. families are critical components of any project and contain objects such as doors, windows, curtain wall systems, furniture, MEP systems, and many more.
- **Short-term solution:** restoring the back **central model** and resaving it as a central model again. The backfile may be a few hours old and require rework.
- **Long-term Solution:** Every BIM participant should install the same version of Revit software; all BIM participants should install all the plugins even if the plugin is not used fully in their respective fields.
- **Permanent Solution:** Using the genuine BIM software

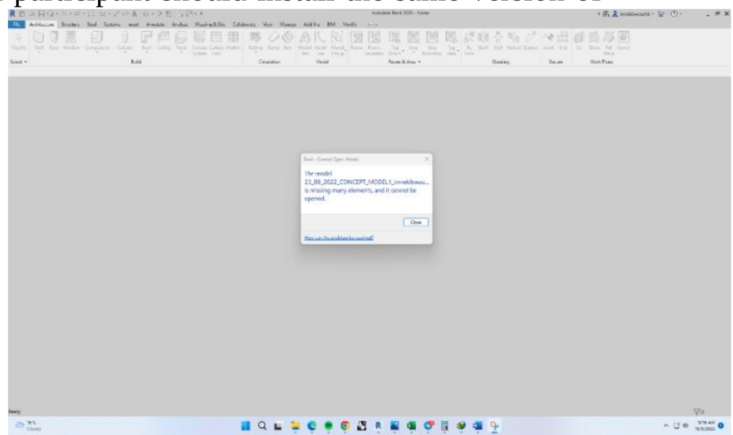

Figure 40 Revit issue

- **Issue 2:** Central model cannot be found, due to a lost network connection or has been moved.
    - **Cause** Moving the model from its location or renaming the model after it was created.
    - **Short-term solution:** create a new central model from the local file by detaching it from the central model.
    - **Long-term Solution:** Do not move rename or tamper with the central model in any way.

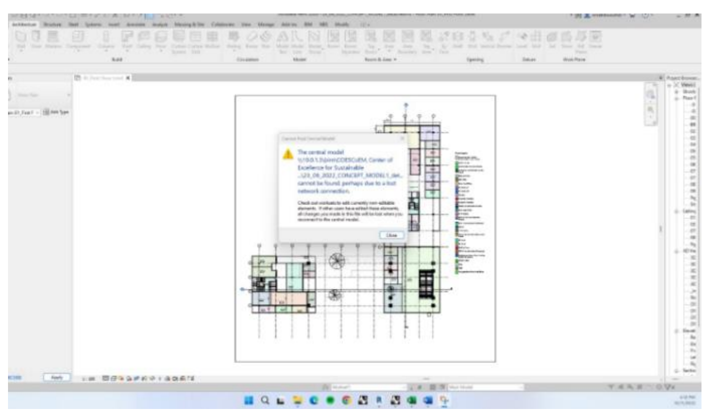

Figure 41 Revit issue

- Issue 3: File not saved
    - **Cause** Saving or synchronizing at the same time with other people
    - **Long-term Solution:** Wait for others to finish to save/synchronize

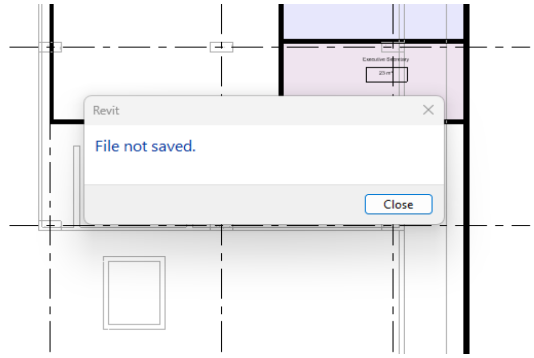

Figure 42 Revit issue

- Issue 4: operation cannot be completed
    - **Cause:** Saving or synchronizing at the same time with other, the network might become busy when numerous people are accessing the central model at the same time.
    - **Short-term Solution:** Wait for a while and try again at less busy time.
    - **Long-term Solution:** Wait for others to finish to save/synchronize coordinate with others and schedule save times.

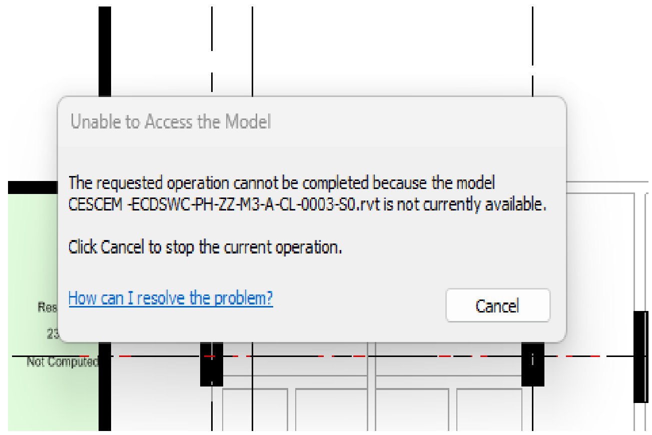

Figure 43 Revit issue

Server

During the project design phase there have been several connection issues. Computers have trouble connecting to the sever where the common data environment is. The server is physically located in the office compound but the administration is at the head office located of site.

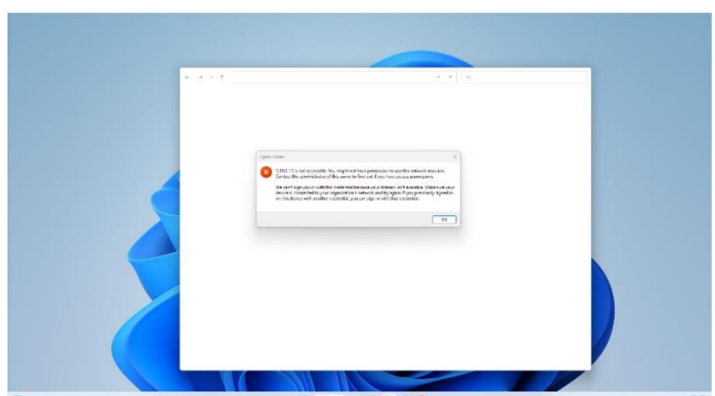

Figure 44 Revit issue

Cause: may be due to several connectivity issues (power outage, too many access request)

Chance of Occurrence: Random undermined

Solution: Locally administrable and controllable server setup.

Server down issues

All files are saved on the server. Everyone is opening the same file and will be working on the same file from the server this cause the server to become busy and at pick hours (during working days) it is very difficult to sync models and corroborate progress amongst teams.

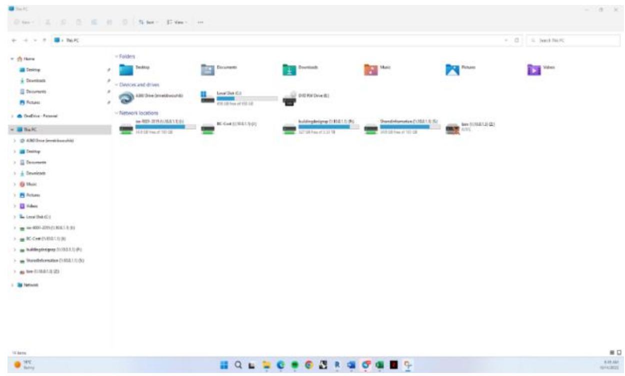

Figure 45 Revit issue

Slow server speed while opening large Central models with all AR, ST, and MEP models federated.

5.3.3 Summery

The adoption of Building Information Modeling (BIM) presented several challenges compared to the conventional construction methods. Firstly, the BIM workflow often proved to be more time-consuming and complex, posing hurdles in project management. Additionally, it demanded a higher allocation of human resources, making it resource-intensive. On the other hand, the conventional approach lacked a streamlined communication and coordination platform, hindering efficiency. Moreover, BIM required a significant upfront investment in acquiring the necessary tools and software for project implementation. Interestingly, both methods displayed a similar completion rate, which predominantly hinged on project timelines rather than the chosen approach. Ultimately, realizing the benefits of BIM necessitated a well-thought-out implementation plan, adequate resources, and unwavering dedication throughout the process, emphasizing the importance of proper planning and commitment in harnessing its potential advantages.

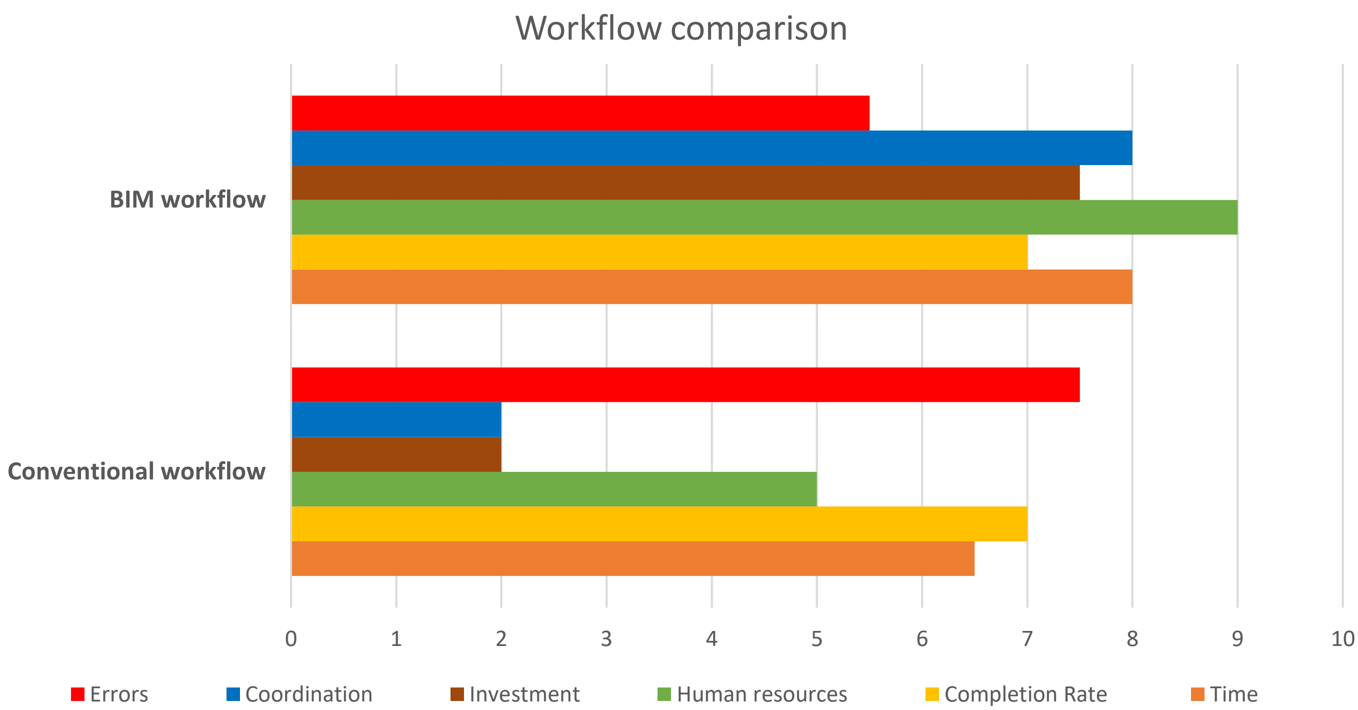

Figure 46 Work flow comparison

5.4 A contextually appropriate BIM implementation

This chapter delves into the development of a contextually appropriate BIM implementation system, drawing insights from the literature review and findings of previous objectives. Three fundamental pillars are explored: the BIM Technological Framework, the Information Requirement Framework, and the BIM Design Workflow. By combining these essential elements, a holistic BIM implementation plan is established, fostering seamless collaboration, data management, and interdisciplinary cooperation. This structured approach enables the firm to optimize the BIM design processes, iterate and improve the system for future projects, and ultimately achieve more efficient and coordinated project outcomes and delivery systems. Through the integration appropriate tools and technologies and standardized data exchange, the organization can confidently navigate BIM implementation and embrace continuous improvement to stay at the forefront of the industry. Ultimately, a well-structured BIM implementation plan fosters innovation, reduces project risks, informed decision making and enhances overall project delivery.

5.4.1 Technological framework

BIM is a data-rich and collaborative approach to building design and construction, which necessitates a robust technological framework with three vital pillars: software, hardware, and network infrastructure (Succar, 2009). The software pillar comprises BIM authoring and coordination tools, enabling stakeholders to create and manage 3D models while facilitating multidisciplinary collaboration. The hardware pillar provides the necessary computational power through high-performance workstations and mobile devices for on-site access to BIM data. Specialized hardware, like 3D laser scanners, contributes to accurate data capture. The network infrastructure pillar fosters seamless communication and real-time collaboration among geographically dispersed teams, with LANs supporting local interactions and WANs connecting different locations. Harmoniously integrating these pillars is crucial for harnessing BIM's full potential, improving efficiency, accuracy, and excellence in the design process, revolutionizing the architecture, engineering, and construction industries, and delivering sustainable, intelligent buildings for the modern world (Succar, 2009).

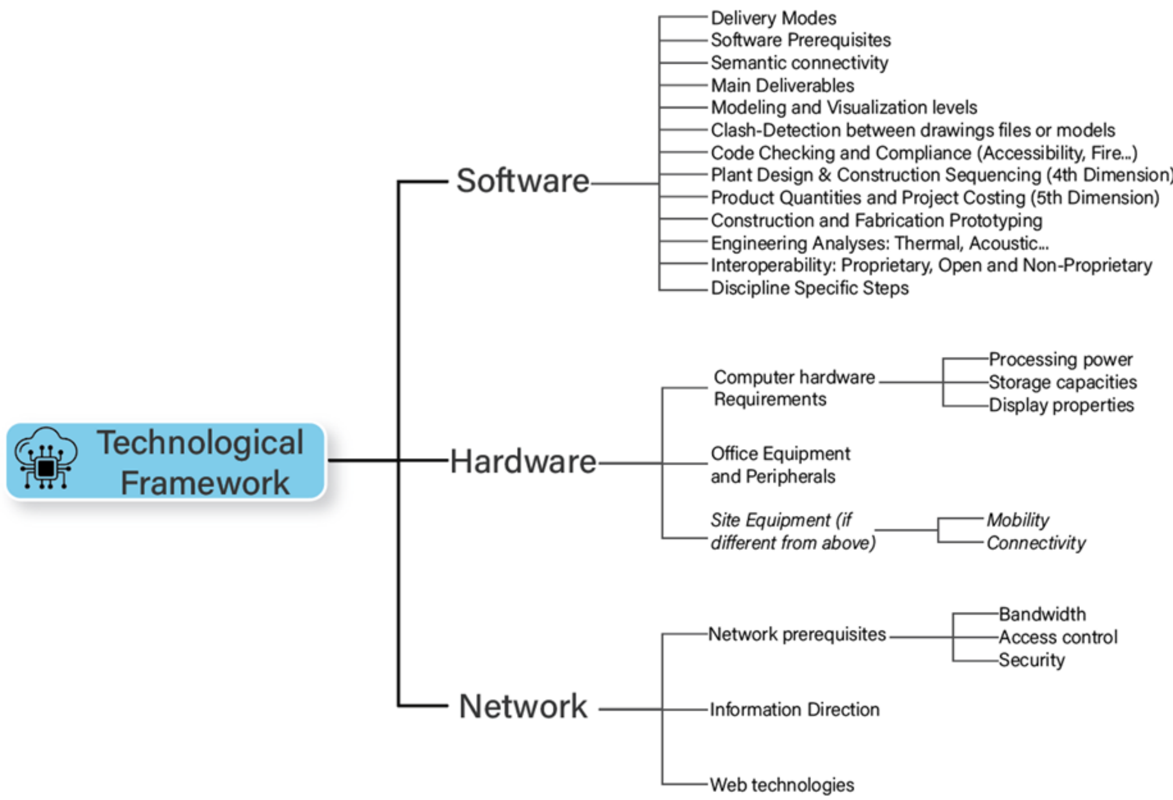

Figure 47 Technological framework based on (Succar, 2009)

Software: BIM software is at the core of the implementation, enabling the creation, collaboration, and management of BIM data throughout the project lifecycle. The key components of the software pillar include:

- **BIM Authoring Tools**: These are the software applications used by architects, engineers, and other stakeholders to create and model the building's digital representation. Some popular BIM authoring tools include Autodesk Revit, Graphisoft ArchiCAD, and Bentley AECOsim.
- **BIM Coordination Tools**: These tools facilitate clash detection and coordination among various disciplines involved in the project, such as architecture, structural engineering, and mechanical, electrical, and plumbing (MEP) systems. Tools like Navisworks and Solibri are commonly used for this purpose.
- **BIM Collaboration Platforms**: These platforms provide a centralized cloud-based environment for collaboration, information sharing, and version control among project stakeholders. Examples include BIM 360 and Trimble Connect.

- **BIM Data Management**: Managing and organizing vast amounts of data generated during the BIM process is essential. This includes managing project files, information exchange formats (IFC), and BIM object libraries.

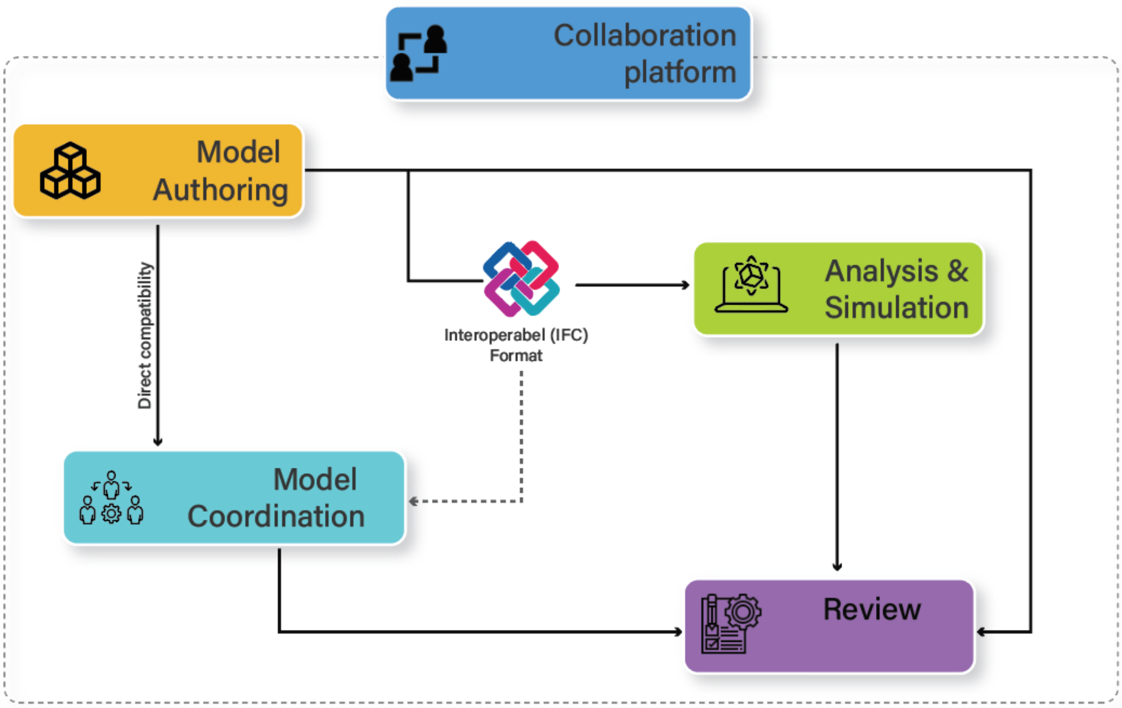

Figure 48 Simplified collaboration chart

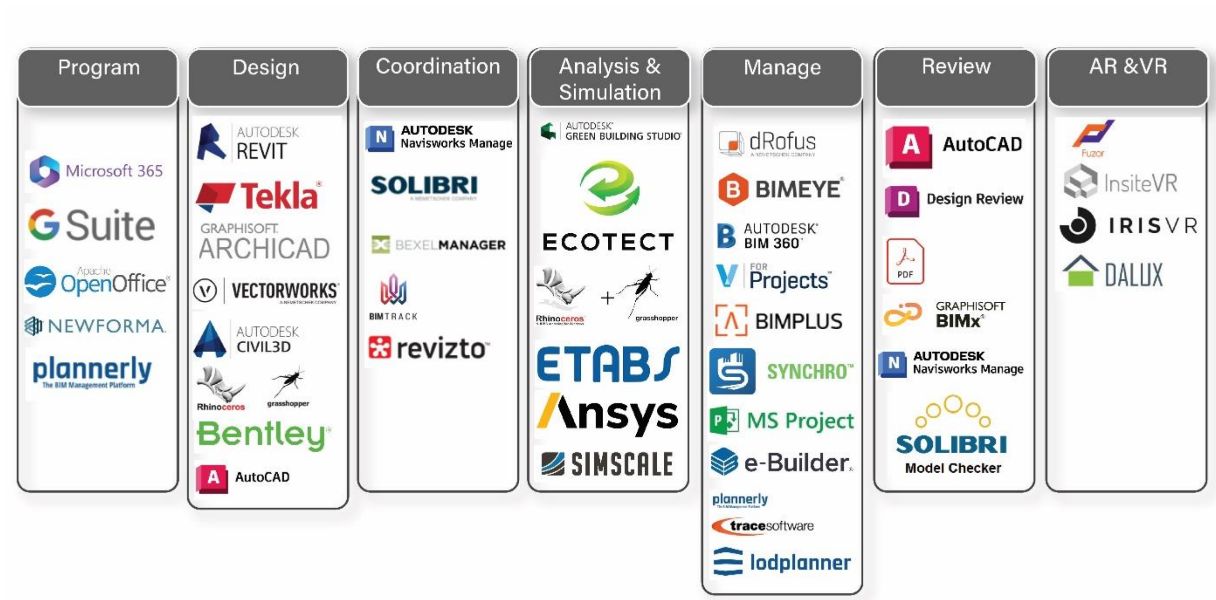

Figure 49 BIM tools A modified version based on (Mohamad Kassem, 2013)

Hardware: BIM implementation demands capable hardware that can handle the computational requirements of running resource-intensive BIM software efficiently. The hardware pillar includes:

- **Workstations:** High-performance computers equipped with powerful processors, ample RAM, and high-end graphics cards. Additionally, a reliable internet connection is essential for uploading and accessing large BIM models stored in the cloud. Investing in cutting-edge hardware not only improves the speed and performance of BIM software but also ensures a seamless workflow.
- **Mobile Devices:** Tablets and laptops with high processing power, battery life, and durable construction are essential for on-site access to BIM data and collaboration tools. These devices improve efficiency, reduce errors, and enhance productivity and flexibility for construction professionals by providing real-time updates and communication.
- **Scanners and Sensors:** 3D laser scanners and sensors capture site conditions and generate accurate BIM models. These technologies enable precise measurements and reduce errors between virtual and physical environments. Investment in high-quality scanners and sensors improves BIM model accuracy and reliability, ultimately leading to better project outcomes.
- **Augmented Reality (AR) and Virtual Reality (VR) Devices:** AR and VR devices improve BIM visualization and understanding during design review and construction planning. These devices allow stakeholders to interact in a realistic virtual environment, enhancing communication and collaboration among teams. They also make complex design concepts more intuitive and user-friendly, making it easier for non-technical stakeholders to understand and provide input. Overall, integrating AR and VR devices in the BIM process enhances project coordination and decision-making.

Network Infrastructure: A robust network infrastructure is essential for facilitating seamless communication and collaboration among project team members, especially in geographically dispersed settings. The network infrastructure pillar comprises:

- **Local Area Network (LAN):** A LAN connects devices within a confined geographical area, such as an office or construction site, to enable fast data transfer and communication between team members.

- **A Wide Area Network (WAN):** Connects multiple LANs across different locations, enabling efficient sharing of BIM data and communication between teams. A strong WAN ensures secure and reliable connectivity, enabling real-time collaboration and data sharing. Together, LANs and WANs form the backbone of a project's network infrastructure, providing seamless communication and efficient workflow.
- **Cloud-based networking:** A cloud computing technology to store, manage, and share data and facilitate real-time collaboration among project stakeholders. It provides a centralized and scalable platform accessible via the internet, enabling teams to collaborate efficiently, access up-to-date project information, and streamline communication and decision-making throughout the entire construction project lifecycle.
- **Internet Connectivity:** Reliable and high-speed internet access is crucial for cloud-based collaboration and BIM data access. Without connectivity, stakeholders cannot collaborate in real-time, making informed decisions and ensuring accurate project planning. A stable internet connection maximizes project efficiency.
- **Security Measures:** Strong network security measures, like firewalls and encryption, are crucial for safeguarding sensitive BIM data from unauthorized access and cyber threats. Robust security measures in cloud-based collaboration, including data encryption, access controls, and regular audits, ensure the integrity and confidentiality of project information, building trust among team members and promoting secure communication and decision-making.

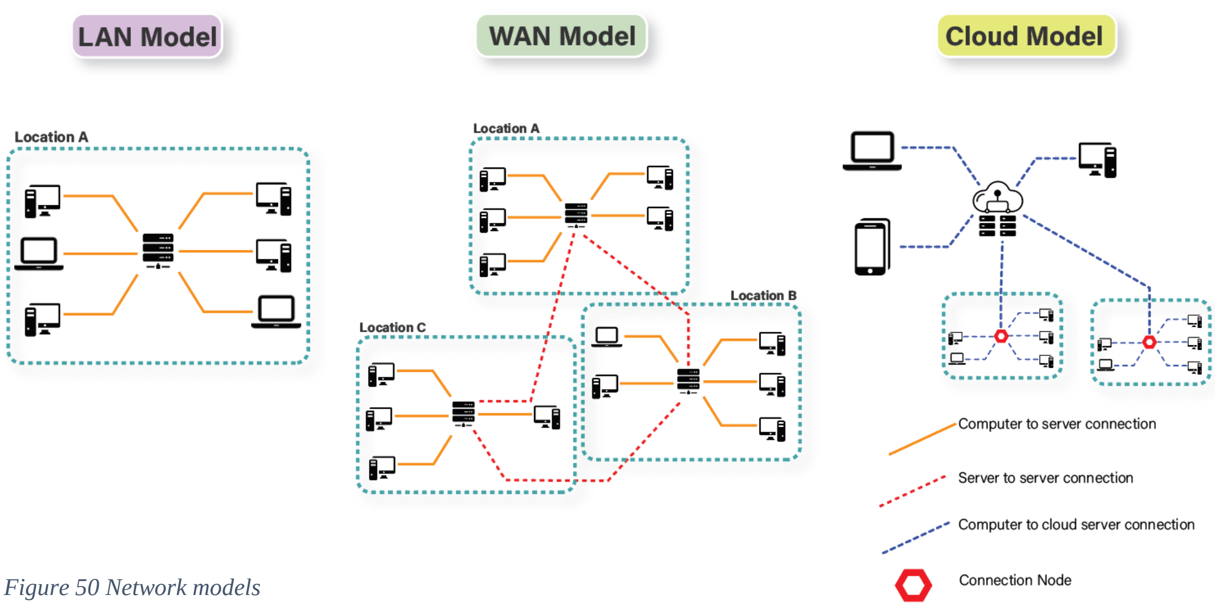

Figure 50 Network models

BIM networking involves connecting teams and stakeholders to facilitate efficient collaboration and data exchange within Building Information Modeling projects. Wide Area Networks (WANs) connect geographically dispersed locations, enabling real-time access to BIM data but may suffer from slower transfer speeds and potential interruptions. Local Area Networks (LANs) provide fast and efficient data exchange within a confined geographical area, but they are limited to a specific location. Cloud-based networking relies on internet-accessible cloud platforms, offering real-time collaboration from anywhere, centralized data storage, and scalability, but it requires reliable internet connectivity and data security measures. The choice of networking approach depends on project scale, team distribution, and data security requirements.

Characteristic	***WAN***	***LAN***	***Cloud-based***
Range	Wide area	Local area	Global
Speed	Slower than LAN	Faster than WAN	Varies depending on the cloud provider
Security	Less secure than LAN	More secure than WAN	Varies depending on the cloud provider
Cost	More expensive than LAN	Less expensive than WAN	Varies depending on the cloud provider
Ease of use	More difficult to use than LAN	Easier to use than WAN	Easiest to use
Scalability	Scalable to accommodate large projects	Not as scalable as WAN	Scalable to accommodate large projects
Collaboration	Can be difficult to collaborate on large projects	Easier to collaborate on large projects	Easier to collaborate on large projects

Table 4 Network models comparison

To select the right BIM tools and platforms for a project, it is essential to understand its scope and complexity, as some projects may require advanced capabilities for intricate designs and data integration, while others may require simpler solutions. With a plethora of BIM-enabled tools and platforms available in the market, choosing the most appropriate ones for a company and project becomes a critical decision.

- **Project Scope and Complexity:** Thoroughly understand the project's scope and complexity. Some projects may require advanced BIM capabilities to handle intricate designs and extensive data integration, while others may be better suited for simpler solutions. Analyzing the specific requirements of the project will help identify the tools that align with the project's unique demands.

- **Collaboration and Interoperability:** It is crucial to choose tools and platforms that support seamless interoperability between different software systems. This ensures that delivery teams can easily share and access data without encountering compatibility issues, reducing time wastage and errors.
- **Scalability and Flexibility:** As projects progress and evolve, the selected BIM tools must be scalable to accommodate changes and expansions. Choosing flexible platforms that can adapt to varying project needs will safeguard against potential roadblocks in the future.
- **User Experience and Training:** The proficiency of the project team in using the selected tools and platforms. User-friendly interfaces and extensive training resources can significantly reduce the learning curve and improve productivity. Evaluating the usability and availability of training support is essential during the decision-making process.
- **Cost and Budget Considerations**: BIM-enabled tools and platforms can range from open-source solutions to high-end, proprietary software with advanced features. Companies must strike a balance between the functionality required for the project and the available budget. Considering the long-term benefits of investing in more robust BIM tools may outweigh the initial cost.
- **Integration with Existing Workflows:** For companies with established workflows and software systems, integrating BIM tools seamlessly is critical. Ensuring that the selected BIM tools can easily integrate with existing software will minimize disruptions and foster a smooth transition.
- **Technical Support and Updates:** Regular updates and technical support are essential for keeping BIM tools up-to-date and addressing any potential issues that may arise during the project. Companies should evaluate the reliability and responsiveness of the tool's support team to ensure continuous and efficient project operations.
- **Security and Data Protection:** BIM involves handling sensitive project data, so security measures must be a top priority. Companies should assess the data protection features offered by BIM tools and platforms to safeguard against potential breaches and unauthorized access.

Selecting the right BIM-enabled tools and platforms for a company and project is a multifaceted process that requires careful analysis of project requirements, user needs, budget constraints, and integration capabilities. By considering the factors mentioned above, companies can make informed decisions and ensure successful BIM implementation, leading to more efficient project management and improved collaboration among stakeholders.

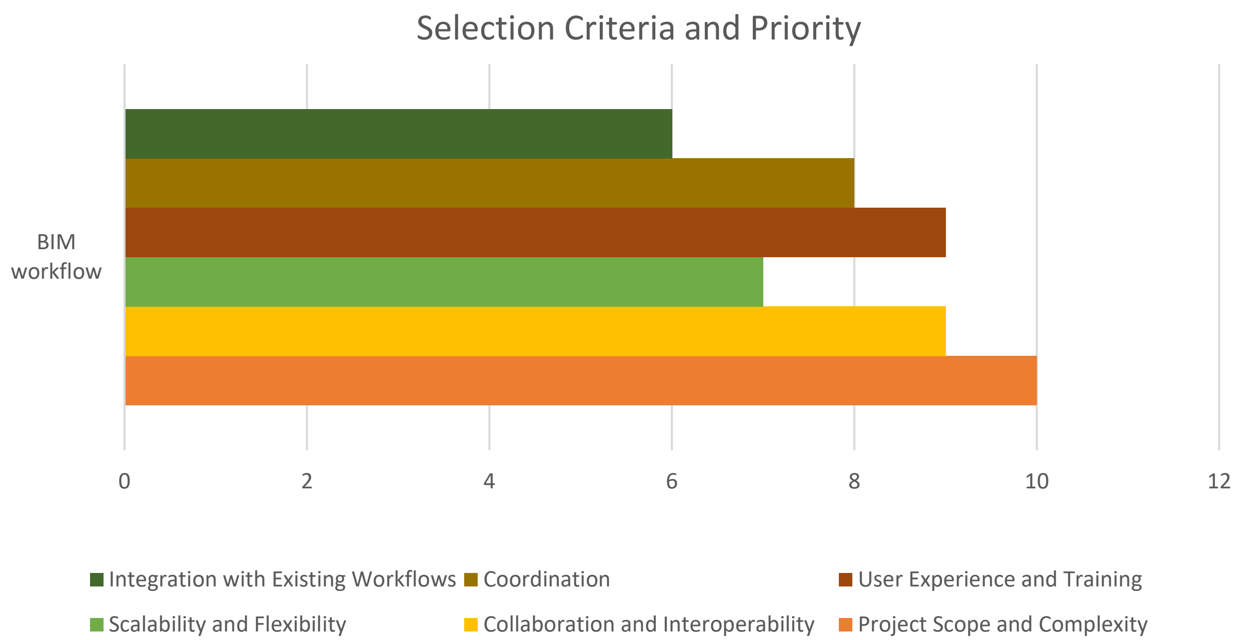

Figure 51 Selection Criteria and Priority for collaborative network infrastructure

5.4.2 Information management framework

The second major aspect revolves around developing an efficient data exchange framework. The ability to share, access, and modify BIM data seamlessly among stakeholders is paramount. Standardizing data formats, utilizing open BIM standards (such as IFC), and implementing collaborative platforms foster better communication and coordination between various project participants. A well-defined information management framework not only minimizes errors and redundancies but also improves decision-making throughout the project lifecycle.

The ISO 19650 *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling:* standard is a set of guidelines that outline best practices for managing information throughout the project lifecycle. It includes recommendations for how to structure the CDE, how to manage information requirements and document workflows, and how to ensure data security and privacy. The data exchange framework in this section was developed by using the principles and guidelines derived from this international standard, ensuring that data management is standardized and efficient. This framework establishes clear protocols for data sharing, version control, and collaboration between project participants. By aligning with the ISO 19650 standard, ECDSWC can streamline their information management processes and enhance the overall quality and reliability of project data.

In Building Information Modeling (BIM), information requirements refer to the specific data and information needed to support the design, construction, operation, and maintenance of a building or infrastructure project throughout its lifecycle. There are different types of information requirements as shown below:

- **OIR**: Organizational Information Requirements is a document that defines the information requirements of an organization for asset management systems and other organizational functions. The OIR is an organization-level document, as opposed to a project-level document (International Organization for Standardization, 2019).
- **PIR:** Project information requirements is a document that defines the information that is required to inform key decisions, at specified timeframes during the project's life cycle. The PIR is created by the project owner or client, and it is used to guide the creation of the Information Delivery Plan (IDP). In the context of Ethiopia, it is unlikely that the client is going to be versed in BIM protocols, and such tasks will inevitability fall on the consultant (International Organization for Standardization, 2019).
- **AIR:** Asset information requirements are the graphical and non-graphical data, information, and documentation needed for the lifetime operation and management of a built asset. The AIR is a document that defines the specific information requirements for a particular asset, and it is used to guide the creation of the Asset Information Model (AIM) (International Organization for Standardization, 2019).
- **EIR:** Exchange Information Requirements is a document that defines the information that needs to be exchanged between different parties involved in a BIM project. The EIR is used to ensure that all parties involved in the project have a clear understanding of the information that needs to be exchanged, and the format in which it needs to be exchanged (International Organization for Standardization, 2019).

The different types of information requirements and information models

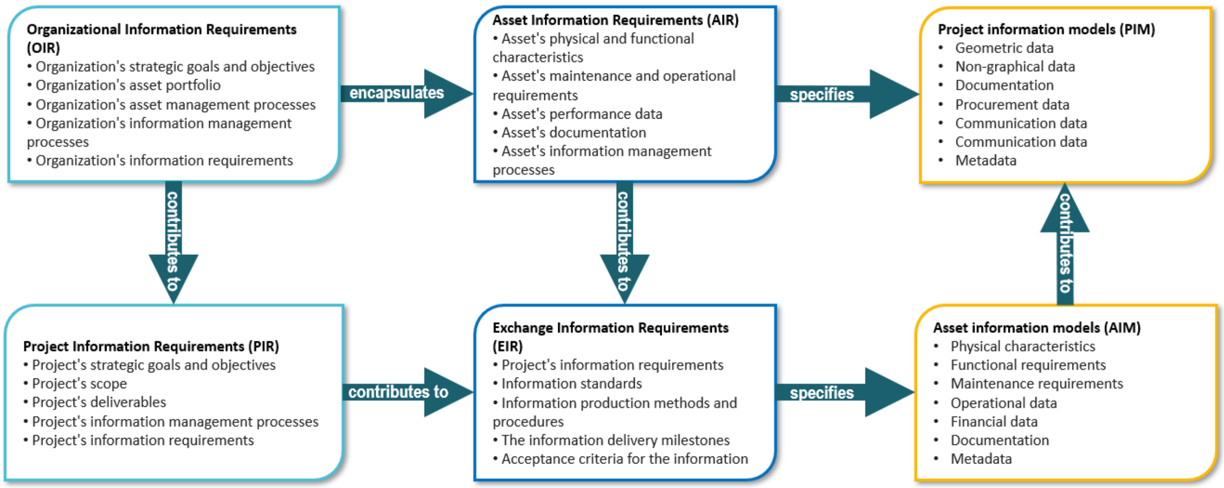

Figure 52 Information requirements in BIM A modified version based on BS EN ISO 19650-1:2018

Asset information models (AIM) and project information models (PIM) are structured repositories of information for decision-making in the entire life cycle of a built environment asset. (International Organization for Standardization, 2019) These models store both structured and unstructured data, including databases, schedules, and geometrical models. PIM provides information for AIM, which includes models, documents, and structured data for an asset's operational phase (Godager, 2022). AIM includes the data required to support strategic and ongoing asset management processes of the appointing party. The asset management system and its effects must be connected to AIM, and various roles and individuals must be connected to the application of AIM for success. Pre-existing asset information is crucial in PIM for projects on existing assets or undeveloped sites, as it informs decisions about project scope, design, and construction methods. The transfer of information between AIM and PIM is an essential part of the information management process, occurring at the start and end of a project to ensure the most up-to-date information is available to stakeholders.

Teams and Roles: In a BIM information management system, the flow of information between different parties needs to have an organized structure so that each party and individual has a clear understanding of the communication path among them (Godager, 2022). By assigning specific roles and information paths, it becomes easier to track the flow of information. The interface between parties and teams involved in a project is depicted in the figure below. These roles should be assigned to parties regardless of whether a formal agreement exists or not; even within a single organization or group.

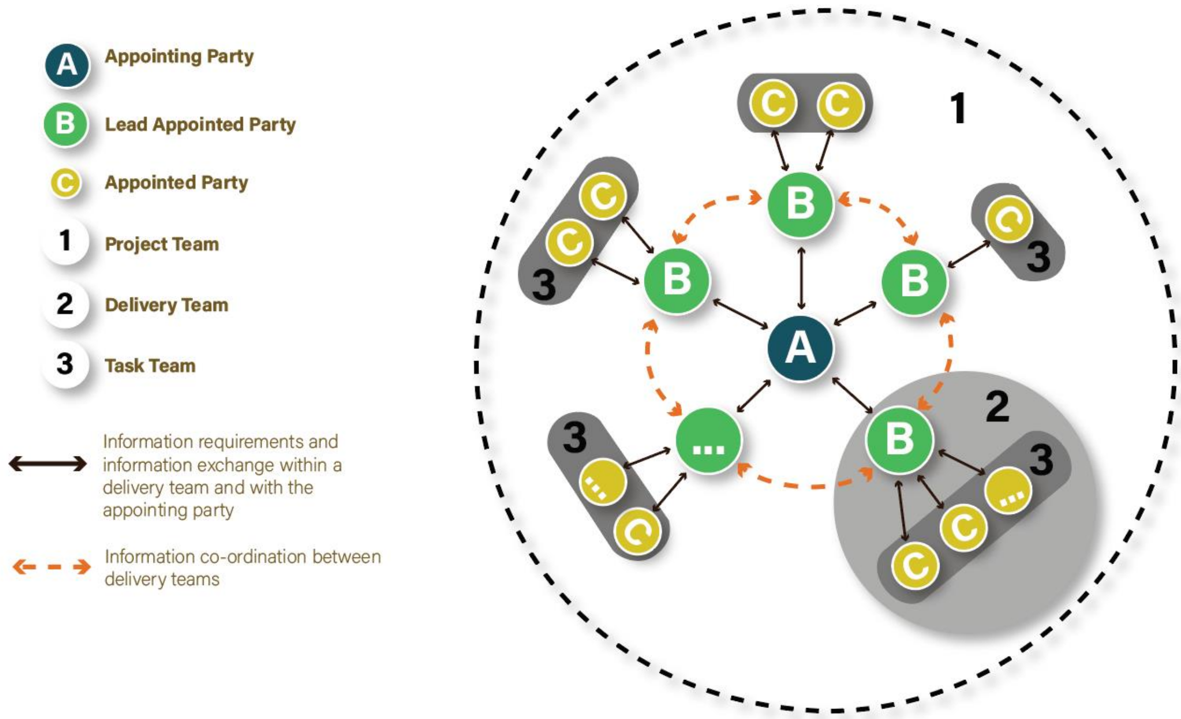

Figure 53 Teams & Roles A simplified version based on BS EN ISO 19650

- The appointing party **(A)** is the client, owner, or a party assigned the role by the owner/client.
- The lead appointed party **(B)** that works on coordinating the production and delivery of information according to an agreed delivery plan. The lead appointed party could be one contractor or a design firm.
- The appointed party **(C)** is the provider of information agreed upon. The appointed party could be a sub-contractor or design team.

- The project team **(1)** is responsible for the overall planning, coordination, and execution of the project. Defines the project scope, develops the project plan, manages the budget and schedule, and ensures that the project meets the client's requirements.
- Delivery Team **(2)** is responsible for the actual design and construction of the project. Coordinates the work of the subcontractors, ensures that the project is built to the agreed-upon standards, and manages the quality of the work.
- The task team **(3)** is responsible for a specific task or discipline within the project. Develops the design, specifications, and construction documents for their assigned task, and manages the execution of the work.

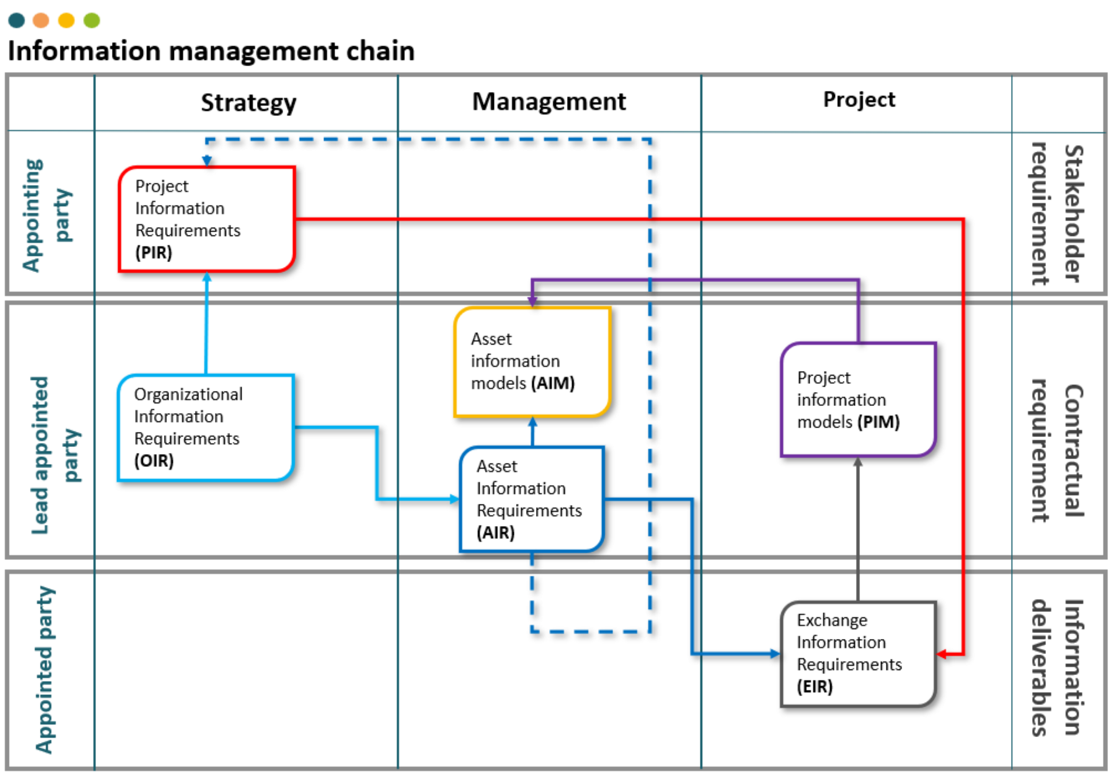

Figure 54 Information management chain based on BS EN ISO 19650

Information delivery planning is the responsibility of each lead appointed party and appointed party. Plans should address information requirements, timelines, methods, coordination, specifics, individuals responsible, and intended recipients. Effective planning should be done before the appointment of parties, followed by mobilization and additional planning if necessary. The delivery team must review information management solutions, ensure necessary appointment conditions are met, processes are in place, and the team possesses the required skills and competencies. Training should be provided, and information exchanges should occur through predefined channels. Delivering information in accordance with specified requirements is a criterion for project or asset management activity completion.

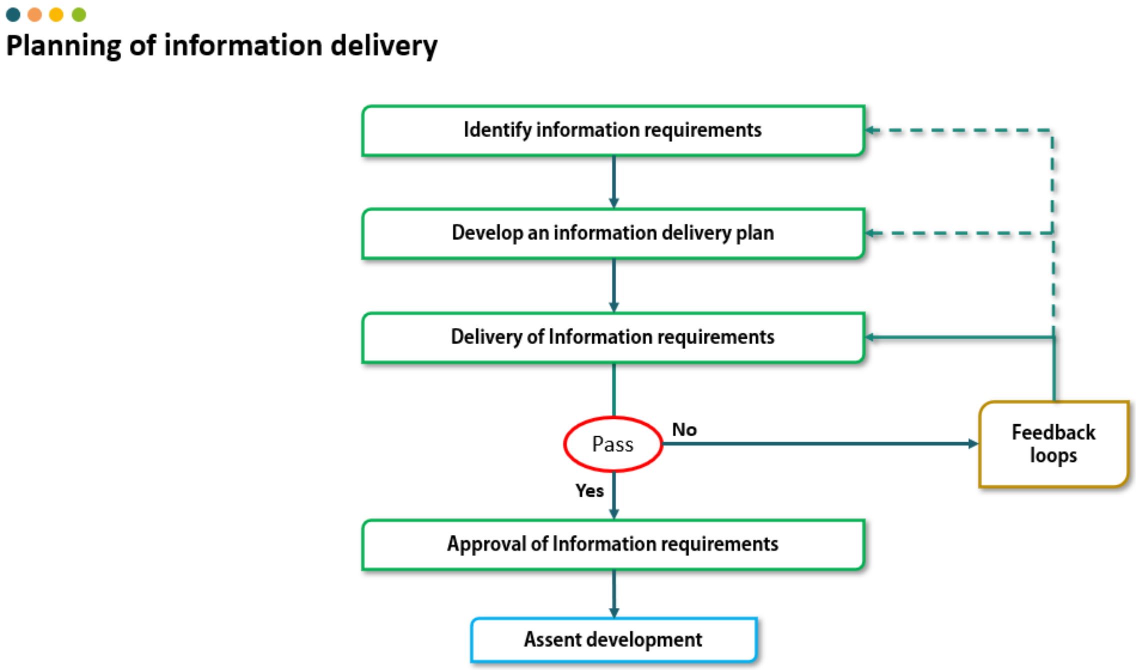

Figure 55 Planning for information delivery: based on BS EN ISO 19650

The appointing party must define essential information for an asset's or project's successful execution throughout its life cycle. These requirements are shared with potential lead-appointed parties during the procurement process, who must respond to them. The appointing party reviews their responses before making a final decision. Each lead appointed party manages and develops the information, incorporating it into their AIR or PIR plans. Feedback loops are established to revise information deliverables as necessary. A documented risk assessment for information delivery is included for effective risk management. The information requirements are thoughtfully designed to address critical questions at various stages of the asset's delivery and operation, enabling well-informed decision-making. An information delivery plan is formulated for each lead-appointed party involved in asset management or project delivery activities, including parallel appointments for design, construction, and other services (International Organization for Standardization, 2019).

Ethiopia's adoption of BIM presents challenges, particularly in terms of client familiarity with BIM protocols and the allocation of responsibilities among involved parties. As BIM adoption becomes more prevalent in the country, it is likely that clients, who are the appointing parties, may not possess a comprehensive understanding of BIM protocols.

One probable scenario is that clients will appoint an intermediary entity to act on their behalf and handle their BIM-related responsibilities. This intermediary could be a BIM consultancy or a project management firm with expertise in BIM implementation. While this approach may alleviate some of the client's burden in dealing with BIM processes directly, it raises the need for clear communication channels and a well-defined scope of work to avoid misunderstandings and potential conflicts. Moreover, there is a possibility that the client might assume the lead appointed party, such as the architectural or engineering firm, will be solely responsible for developing all the BIM information requirements. This assumption could lead to a lack of clarity on the division of responsibilities between the client and the lead appointed party, potentially resulting in delays, inefficiencies, and frustration during the project execution.

To address these potential challenges and avoid conflicts of interest, it is crucial to establish a clear distinction between the roles and responsibilities of the client and the lead appointed party while formulating a collaborative framework that ensures effective communication and coordination.

The Common Data Environment

A CDE solution and workflow are essential for managing information during asset management and project delivery. During the delivery phase, the CDE solution supports information management processes (Burgess, 2023). The Project Information Model (PIM) and Asset Information Model (AIM) are stored within the CDE, accessible to all project team members (Burgess, 2023). The PIM contains design and construction-related information, while the AIM includes additional information for ongoing asset management and maintenance. Both PIM and AIM are managed and shared within a centralized Common Data Environment (CDE), ensuring collaboration and efficient project delivery (Burgess, 2023). At the end of a project, information containers for asset management should be moved from the PIM to the AIM, while remaining projects in formation containers should be retained as read-only for dispute resolution and learning. The timescale for retaining project information containers should be defined in the EIR.

The current revision of each information container within the CDE should be in one of the following three states: read-only, read-write, and write-only (Burgess, 2023).

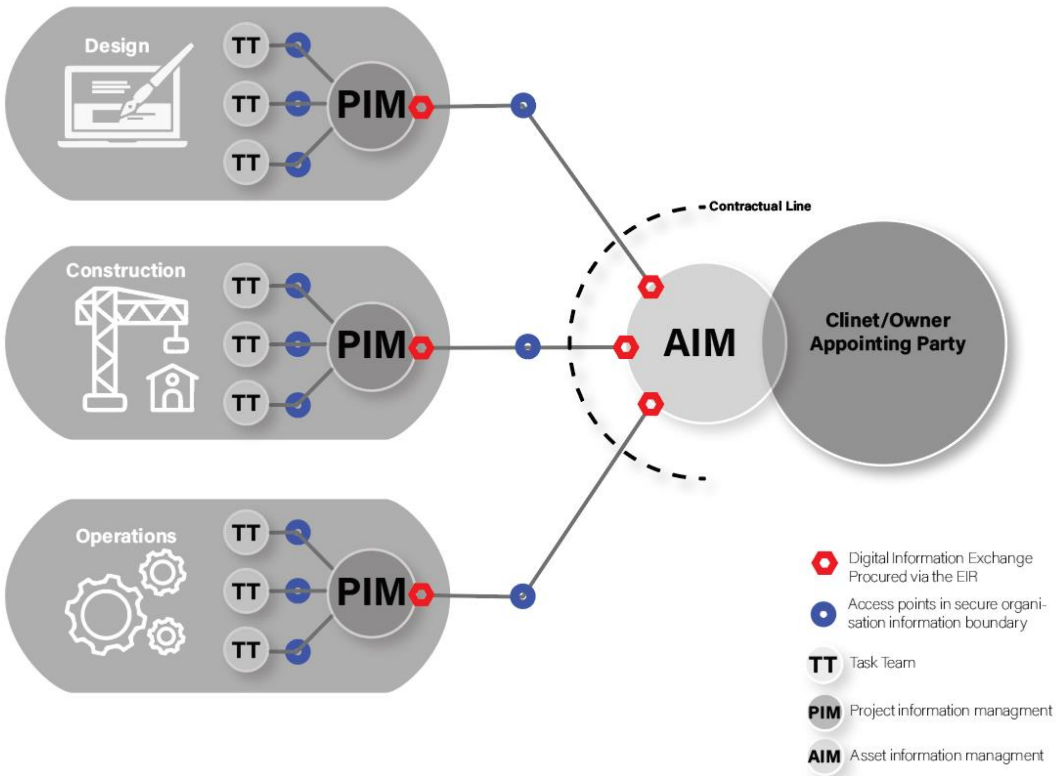

Figure 56 The Asset information model and project information model based on (Burgess, 2023)

Work in Progress: WIP refers to the stage where information is actively being created, modified, or updated by task teams, such as architects, engineers, contractors, and subcontractors. The WIP stage is dynamic and represents the most up-to-date and evolving state of the project data (British Standards Institution, 2020).

Shared: This stage occurs when the WIP data is ready to be shared with other authorized task teams or stakeholders. At this point, the data is disseminated through a controlled process. Shared data is accessible to relevant parties for review, coordination, and collaboration, but it is not yet considered the final version (British Standards Institution, 2020).

Published: This refers to the stage where the shared data is formally approved and released as a controlled and official version. Published data is typically frozen and considered the official representation of a specific milestone or deliverable. This version is no longer subject to changes unless specific procedures for revision are followed. Published data is often used for coordination, reviews, and approvals (British Standards Institution, 2020).

Archived: This stage is reached when a particular phase of the project is completed, or when data is no longer actively needed for the current project scope. Archived data is retained for historical and reference purposes, complying with project documentation and record requirements. It is stored securely and can be retrieved if needed for future reference, audits, or potential future projects (British Standards Institution, 2020).

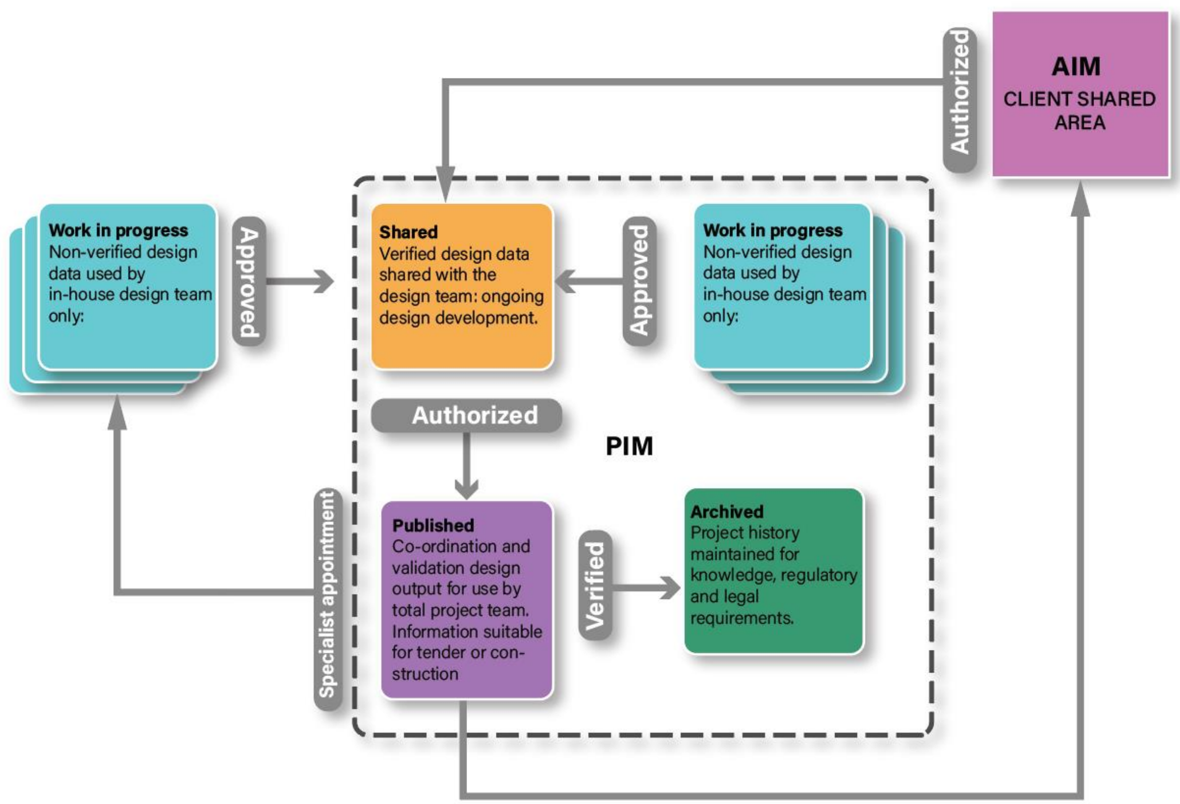

Figure 57 An extended common data environment based on ISO19650

The best type of CDE for a particular project will depend on the specific needs of the project team. If the project team needs to access data from anywhere, a cloud-based CDE may be the best option. If the project team needs to have more control over security and compliance, a local server-based CDE may be a better choice (Mohamad Kassem, 2013).

Feature	Cloud-based CDE	Local server-based CDE
Access	Can be accessed from anywhere with an internet connection	Access is limited to users on the local network
Scalability	Scalable to accommodate large projects	Not as scalable as cloud-based CDEs
Security	Variable security and compliance with industry standards	More control over security and compliance
Cost	Cost-effective	More expensive to set up and maintain initially

Table 5 Comparison of different CDE platforms

5.4.3 BIM based design workflow

A well-structured BIM design workflow involves defining clear roles, responsibilities, and workflows for all team members, from architects to engineers and managers. This collaborative environment is aimed to fostering interdisciplinary cooperation, allowing for simultaneous design modifications and model sharing protocols, leading to more efficient and coordinated project outcomes (Francois Levy, 2019). A well-structured BIM design workflow ensures effective communication and coordination between different disciplines, increasing productivity and reducing errors (M. Kassem, 2015). This approach promotes innovation and creativity, allowing the real-time sharing of ideas and fostering a culture of continuous improvement. Simultaneous design modifications and clash detection help identify and resolve potential

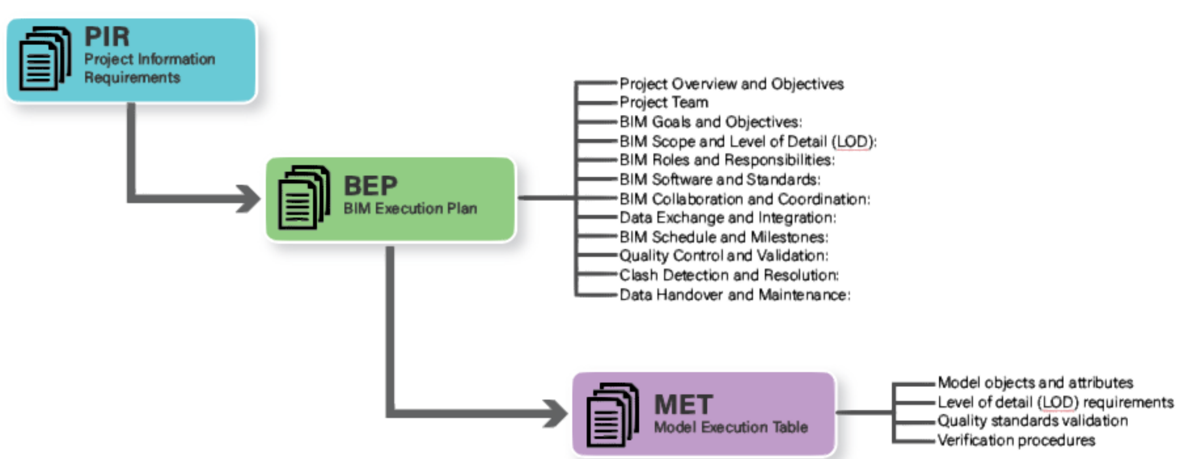

Figure 58 BIM Design workflow planning

conflicts early on, saving time and resources. Overall, a well-structured BIM design workflow is essential for successful project outcomes (M. Kassem, 2015).

A well-structured BIM design workflow hinges on two main guiding documents the BIM Execution Plan (BEP) & Model Execution Table (MET) (Bimal Kumar, 2019). These documents serve as the foundation for effective collaboration and coordination among task teams. The BIM Execution Plan outlines the overall strategy and goals for the project, including the specific BIM deliverables and responsibilities of each team member. On the other hand, the Model Execution Table provides a detailed breakdown of the required model elements, their level of development, and the timeline for their completion. Together, these documents ensure a seamless and efficient BIM design workflow, promoting accurate information exchange and reducing errors and conflicts throughout the project lifecycle.

- **BEP:** A BIM Execution Plan (BEP) is a strategic roadmap for project implementation and management, defining processes, protocols, standards, responsibilities, and deliverables. Its primary purpose is to ensure stakeholders agree on the BIM implementation strategy and facilitate smooth, coordinated project execution (Rafael Sacks, 2018). A BIM Execution Plan consists of several key components, including a project overview, project team, BIM goals, scope, level of detail, roles and responsibilities, software and standards, interdisciplinary collaboration, data exchange and integration, schedule and milestones, quality control and validation, clash detection and resolution, and data handover and maintenance (Eastman, 2011). By establishing clear roles and responsibilities, BEP is aimed facilitate interdisciplinary collaboration, minimize errors, and ensure the successful implementation of BIM technology. The BIM execution plan sometimes referred to as BXP is drafted by gathering input from all participating BIM task teams (Eastman, 2011). Each task team contributes their expertise and knowledge to ensure a comprehensive and well-rounded plan. The BXP outlines the objectives, timelines, and resources required for the successful execution of the BIM project. This collaborative approach ensures that all teams are aligned and working towards a common goal (Eastman, 2011).

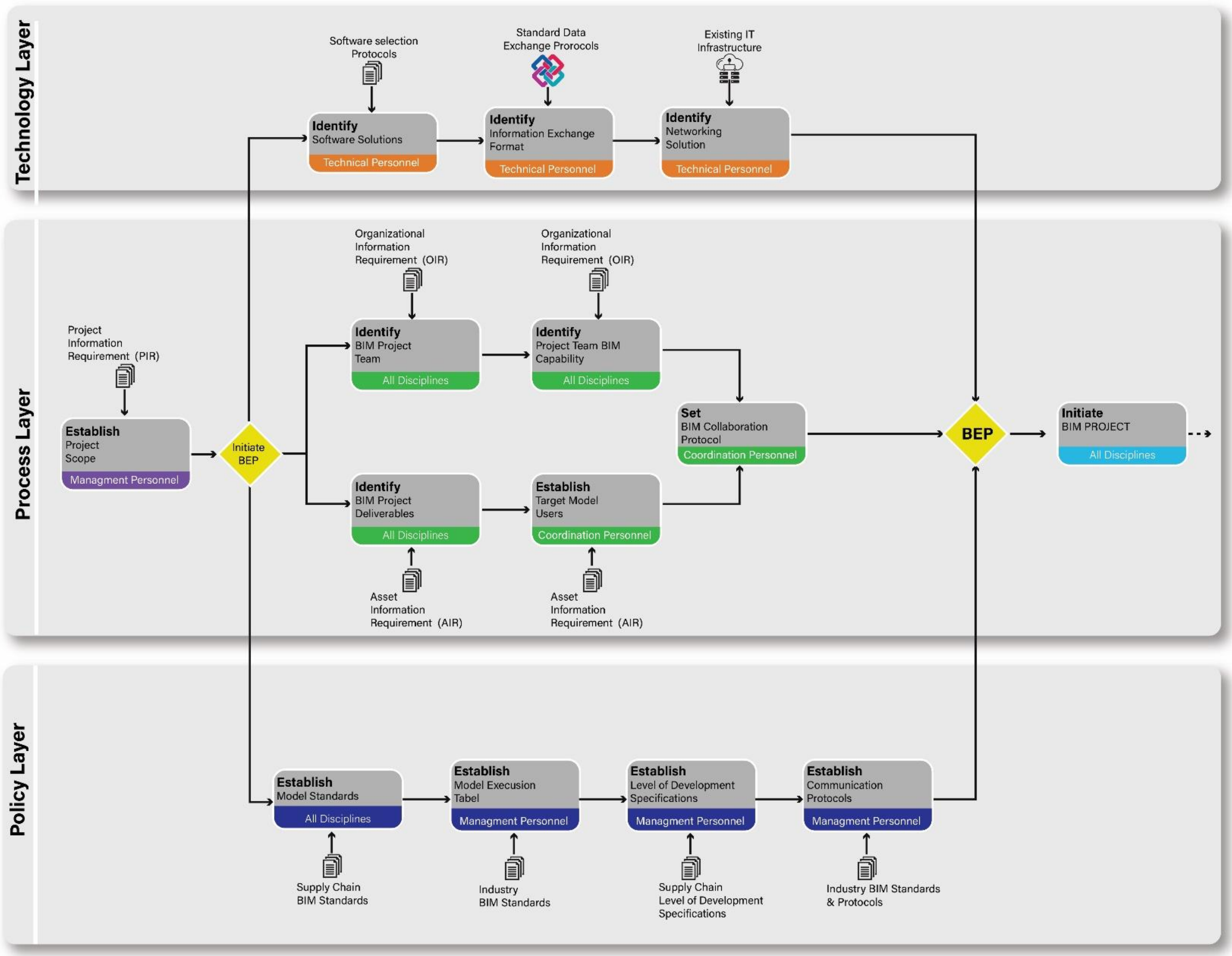

Figure 59 BEP/BXP Scope, adopted from Succar et al. (2013)

MET: Model Execution Table is a document that specifies the content, level of detail, and quality requirements for a BIM model. It includes information such as model objects and attributes, Level of detail (LOD) requirements, quality standards validation and verification procedures (Bimal Kumar, 2019). Model authors update BIM models at specific project milestones, setting objects' size, shape, location, orientation, and quantity according to the MET-specified LOD. They verify required properties and disseminate the MET among practitioners. Model information consumers assess the reliability of information at a given milestone, verifying the author's verification. The Model Element Table from a project BEP serves as a guide for authors and consumers.

Team Roles and Responsibilities: In a BIM project, the roles and responsibilities of different team members can vary depending on the project's size and complexity. For smaller projects, the BIM manager may assimilate the roles of the BIM coordinator, technicians, and data manager. In the same manner, the architects and engineers will also take on the BIM modeling responsibilities (Mohamad Kassem, 2013). This allows for a streamlined process where the BIM manager oversees the clash detection and constructability analysis, as well as coordinates with project stakeholders to optimize design workflows. For larger and more complex projects, a dedicated team of BIM coordinators, technicians, and data managers may be necessary to handle the technical aspects of BIM modeling (Mohamad Kassem, 2013). The architects and engineers can then focus on their respective design and engineering responsibilities while collaborating closely with the BIM team to ensure accurate and efficient project coordination. Below is a general overview of the roles and responsibilities of key BIM team members.

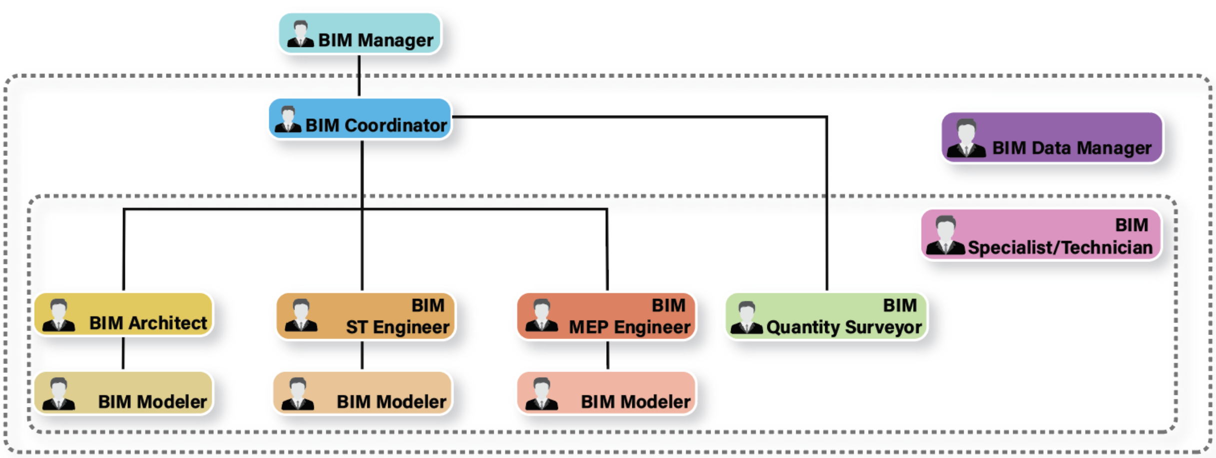

Figure 60 Simplified BIM design teams and roles

- **BIM Manager:** Role: Oversee the entire BIM process and ensure its successful implementation throughout the project lifecycle. Responsibilities: Develop BIM execution plans, develop model execution Table, coordinate disciplines, oversee the modeling process, troubleshoot issues, manage software, updates, and training, and adhere to project timelines and budget constraints (Mohamad Kassem, 2013).
- **BIM Coordinator:** Role: Manage the day-to-day implementation of BIM processes and ensure smooth collaboration between disciplines. Responsibilities: Collaborate with design teams to exchange BIM data, manage clashes, ensure alignment, implement

standards, and hold regular meetings to discuss progress and resolve issues (Mohamad Kassem, 2013).

- **BIM Architect:** Role: Create and manage the architectural BIM model, represent design intent, and coordinate with other disciplines. Responsibilities: Create and coordinate architectural BIM models, collaborate with BIM Coordinator, apply best practices, detect conflicts and manage revisions and updates.
- **BIM Structural Engineers:** Role: Create and manage the structural BIM model, ensuring accuracy and compliance with design requirements. Responsibilities: Develop and integrate structural BIM models, coordinate with architects, MEP engineers, and stakeholders, detect conflicts, optimize design, and update models accordingly.
- **BIM MEP Engineers (Mechanical, Electrical, Plumbing):** Role: Create and manage BIM models for mechanical, electrical, and plumbing systems. Responsibilities: Develop BIM models for MEP systems, coordinate with disciplines, detect clashes, optimize performance through simulations, and update models to reflect design changes.
- **BIM Modeler: Role:** Create detailed BIM models based on design and engineering inputs from various disciplines. Responsibilities: Create accurate BIM models for architectural, structural, or MEP elements, following standards, incorporating design changes, collaborating, and participating in coordination meetings for clash detection and resolution (Mohamad Kassem, 2013).
- **BIM Specialist/Technician:** Role: Provide technical support and expertise in BIM software and tools. Responsibilities: Manage BIM software licenses, ensure compliance, conduct training, and stay updated on latest developments and best practices for team members (Mohamad Kassem, 2013).
- **BIM Data Manager:** Role: Oversee the organization and management of project data and information within the BIM environment. **Responsibilities:** Develop data management protocols, ensure accuracy, integrity, consistency, implement security measures, and manage stakeholder collaboration (Mohamad Kassem, 2013).
- **BIM Document Controller:** Role: Manage and distribute BIM-related documentation and deliverables. Responsibilities: Maintain BIM project files, documentation, and document control procedures for versioning, revision, and distribution to relevant parties (Mohamad Kassem, 2013).

- **BIM Quantity Surveyor/Estimator:** Role: Utilize BIM data to perform quantity take-offs and cost estimation for the project. Responsibilities: Extract BIM data for building elements, integrate into software for accurate cost estimation and quantity surveying, and provide timely estimates (Mohamad Kassem, 2013).
- **BIM Sustainability/Performance Analyst:** Role: Analyze the environmental and energy performance of the building using BIM data. Responsibilities: Utilize BIM data for energy simulations, performance analysis, sustainability evaluation, design improvements, and green building certifications (Mohamad Kassem, 2013).

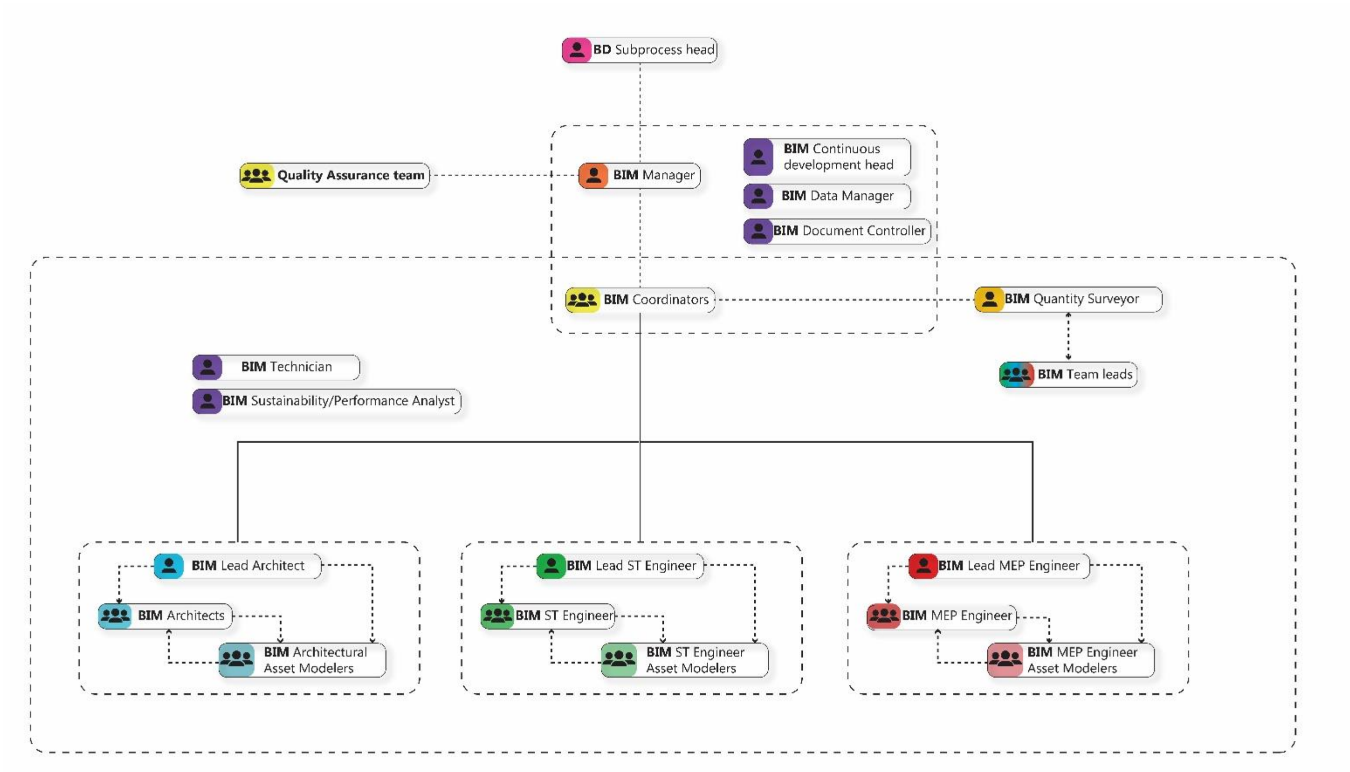

Figure 61 Extended BIM design team's structure

A BIM design task teams' structure may differ based on the organizational structure and from project to project. In some organizations, the BIM design task team may consist of architects, engineers, and modelers who work together closely throughout the entire project (Francois Levy, 2019). However, in other organizations, the team may be more fragmented, with different specialists working on different aspects of the BIM design. Additionally, the composition of the team may vary depending on the specific requirements and complexity of each project. Ultimately, the key is to establish a collaborative and efficient structure that allows for seamless integration and coordination among team members.

BIM Responsibility Matrix: A BIM Responsibility Matrix is a document used in construction and architecture projects to outline the roles and responsibilities of various stakeholders involved in the BIM process (The Royal Institute of British Architects, 2020). BIM is a digital representation of a building's physical and functional characteristics, and its effective implementation requires clear delineation of responsibilities to ensure a coordinated and efficient workflow. The matrix typically includes elements such as Task or Activity, Stakeholder/Role, Responsible (R), Consult (C), Inform (I), Review (Rev), and Approve (App). The primary party responsible for performing the task is the "R" designation, while consultants provide input or guidance (The Royal Institute of British Architects, 2020). Stakeholders should be kept informed about the progress of a task, and the review stage may involve stakeholders reviewing and approving the work completed by the responsible party.

Responsible **(R)** Consult **(C)** Inform **(I)** Review **(Rev)** Approve **(App)**

Task / Activity	Stakeholder Role	Architect	Structural Engineer	MEP Engineer	BIM Coordinator	BIM Manager
BIM Execution Plan (BEP) Development		(C)	(C)	(C)	(C)	(R)
Conceptual Design		(R)	(C)	(C)	(I)	(I)
Site Analysis		(R)	(I)	(I)	(I)	(I)
Preliminary Modelling		(R)	(R)	(R)	(I)	(I)
Structural Analysis		(C)	(R)	(I)	(I)	(C)
Coordination Meeting Schedule		(I)	(I)	(I)	(C)	(R)
MEP Coordination		(I)	(I)	(R)	(R)	(C)
Clash Detection		(C)	(C)	(C)	(R)	(R)
Detail Modelling		(R)	(R)	(R)	(C)	(C)
Energy Analysis		(C)	(I)	(R)	(I)	(I)
Model Review		(I)	(I)	(I)	(C)	(Rev)
Model Updates		(R)	(R)	(R)	(Rev)	(I)
Final Approval		(I)	(I)	(I)	(C)	(App)

Table 6 Simplified BIM responsibility Matrix

There is a detailed BIM Responsibility Matrix document provided by the The Royal Institute of British Architects called the RIBA Plan of Work. This document provides a detailed breakdown of the roles and responsibilities of each party involved in a BIM project. It outlines the specific tasks and deliverables expected from the client, architect, engineer, contractor, and other stakeholders throughout each stage of the project. This document enables all participants to have a clear understanding of their responsibilities, and can be obtained from the official website via the following link: https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work#available-resources

Design Responsibility Matrix incorporating Information Exchanges

Guidance on selection of design objects
(Tip: To hide this row right click on the row and select 'hide')

The aspects of design should be titled and coded using the Uniclass 2015 classification tables for objects such as spaces, elements, systems and products, as appropriate. These tables and a free online digital plan of work tool can be found on the NBS BIM Toolkit website [1]. Technical support articles are provided on on classification [2], and levels of definition [3].

Uniclass 2015 is aligned to ISO 12006-2 [4], and was in part funded by Innovate UK on behalf of the UK Government's BIM Task Group [5]). (All websites are listed in the 'Useful links' worksheet in this document)

		2 - Concept Design			3 - Spatial Coordination			4- Technical Design			4 - Technical Design					
Aspect of design		Design team			Design team			Design team			Contractor			Building contractor		
Classification	Title	Design responsibility	Level of detail (LOD)	Level of information (LOI)	Design responsibility	Level of detail (LOD)	Level of information (LOI)	Design responsibility	Level of detail (LOD)	Level of information (LOI)	Design responsibility	Level of detail (LOD)	Level of information (LOI)	Contractor's designed portion	Collateral Warranty required?	Notes
Ss_15 - EARTHWORKS																
Ss_15_10_30	Excavating and filling systems															
Ss_15_30_50	Masonry repair and renovation systems															
Ss_15_30_90	Timber repair and renovation systems															
Ss_20 - STRUCTURAL SYSTEMS																
Ss_20_05_15	Concrete foundation systems															
Ss_20_05_50	Minor concrete substructure systems															
Ss_20_05_65	Piling systems															
Ss_20_10_70	Shelter systems															
Ss_20_10_75	Structural framing systems															
Ss_25 - WALL AND BARRIER SYSTEMS																
Ss_25_10_20	Curtain walling systems															
Ss_25_10_30	Framed partition systems															
Ss_25_10_32	Framed wall structure systems															
Ss_25_10_35	Framed glazed systems															
Ss_25_11_16	Concrete wall systems															
Ss_25_12_60	Panel cubicle systems															
Ss_25_12_65	Panel partition systems															
Ss_25_12_80	Structural glass wall systems															
Ss_25_13_33	Glass wall systems															
Ss_25_13_50	Masonry wall systems															
Ss_25_14_63	Post, rail and board fence systems															
Ss_25_14_67	Post, wire and mesh fence systems															
Ss_25_15_60	Pedestrian safety barrier and guarding systems															
Ss_25_16_94	Vehicle restraint systems															
Ss_25_20_08	Board cladding systems															
Ss_25_20_14	Composite panel cladding systems															
Ss_25_20_15	Concrete cladding systems															

Figure 62 Responsibility Matrix sourced from RIBA Plan of Work 2020

BIM design phase workflow process map: Architectural, Structural, and MEP (Mechanical, Electrical, and Plumbing) building information modeling workflow process maps are essential visual representations that outline the sequence of steps and activities involved in creating and managing architectural, structural, and MEP models using BIM technology (Mohamad Kassem, 2013). These process maps serve as roadmaps for architects, structural engineers, and other task teams, guiding them through a project's lifecycle from inception to completion.

These maps provide structured frameworks for collaborative design and data-driven decision-making, ensuring efficient workflows and successful project deliveries (Bimal Kumar, 2019).. Each map is presented graphically as a clear and organized flowchart, depicting the various activities and interactions during each stage of the model creation process. Moreover, they highlight the interdependencies between different tasks and assist in identifying data and model sharing coordination steps. By adhering to these roadmaps, architects and task teams can ensure seamless workflows, resulting in high-quality project outcomes.

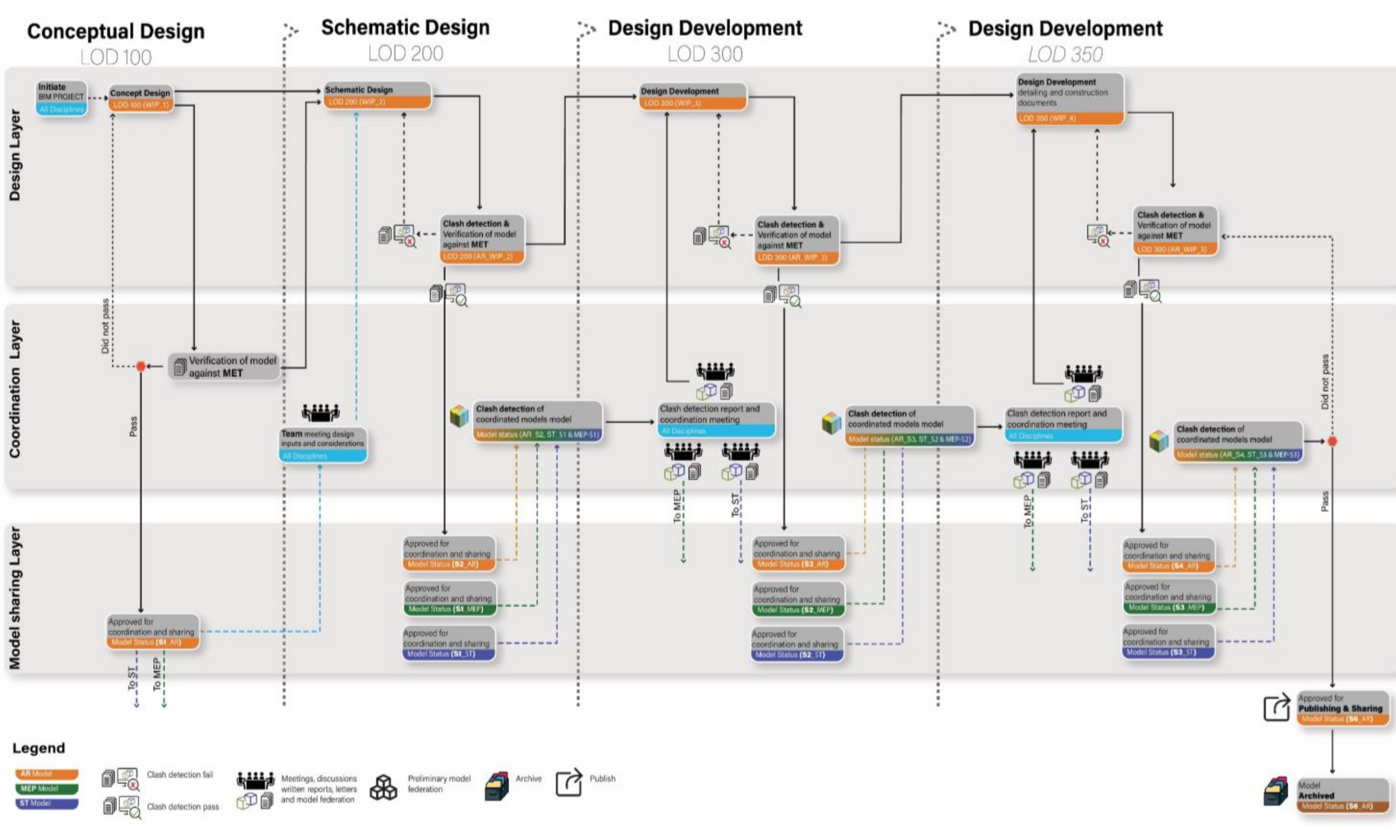

Figure 63 A graphical representation of the BIM architectural design workflow

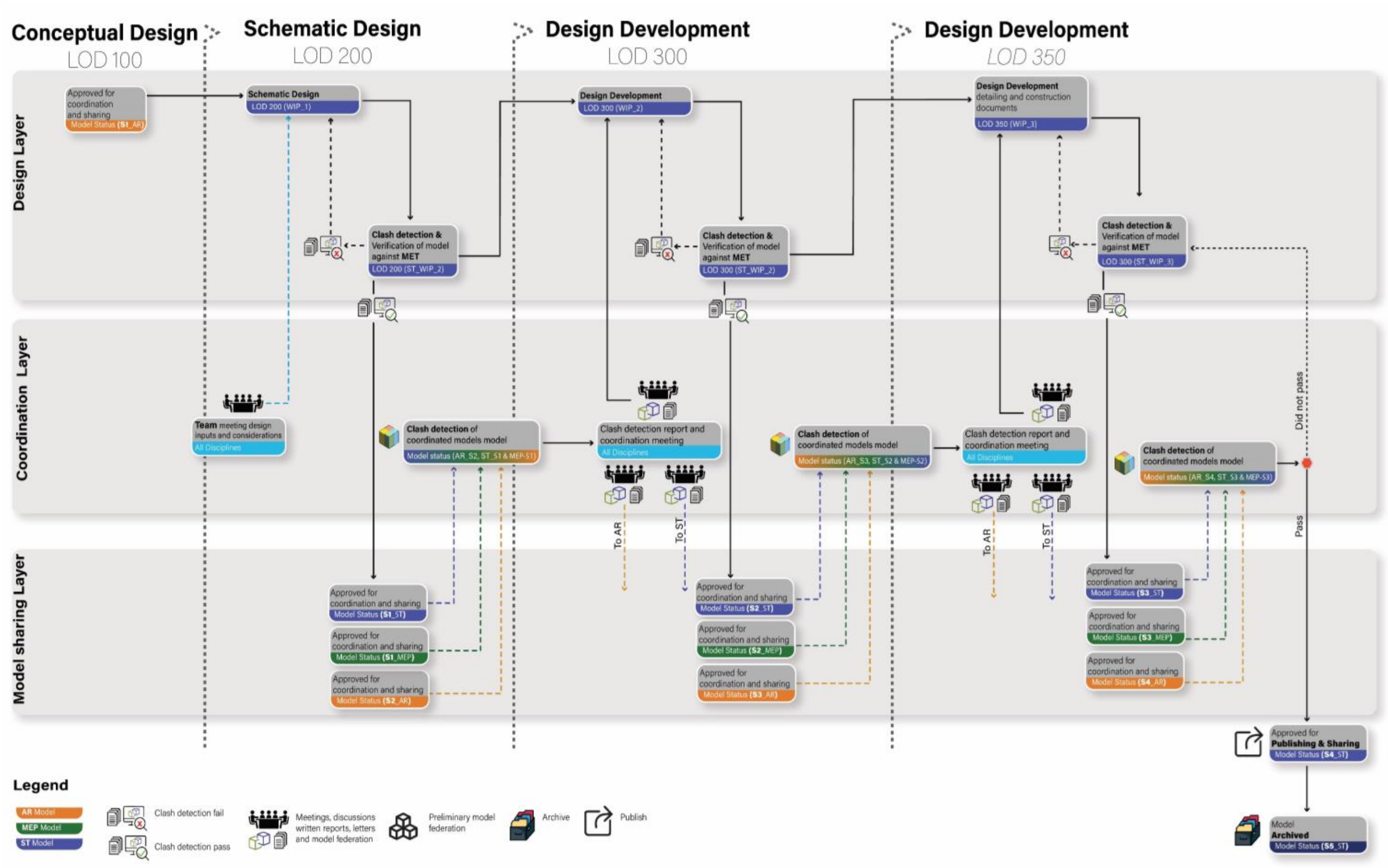

Figure 64 A graphical representation of the BIM structural design workflow

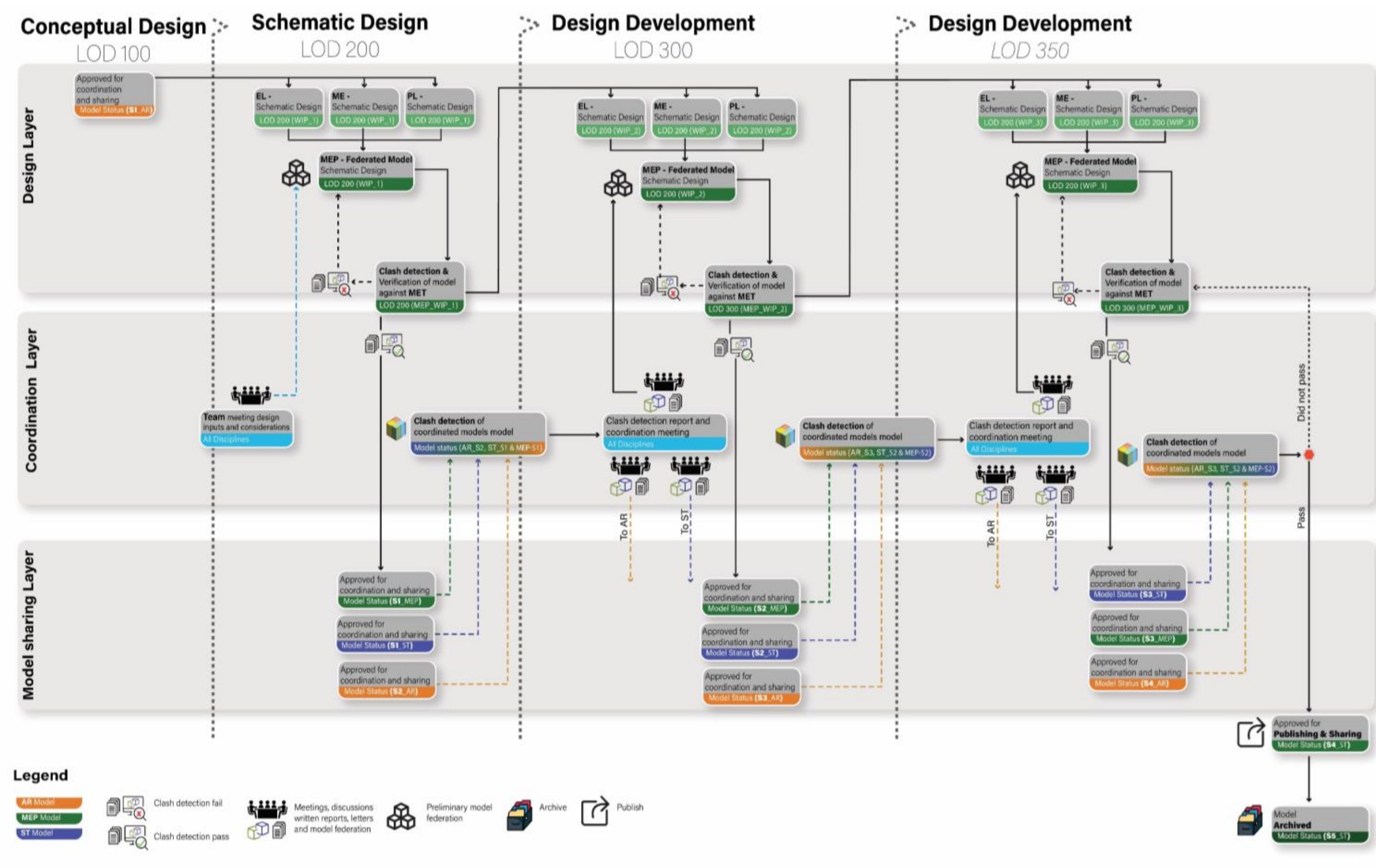

Figure 65 A graphical representation of the BIM MEP design workflow

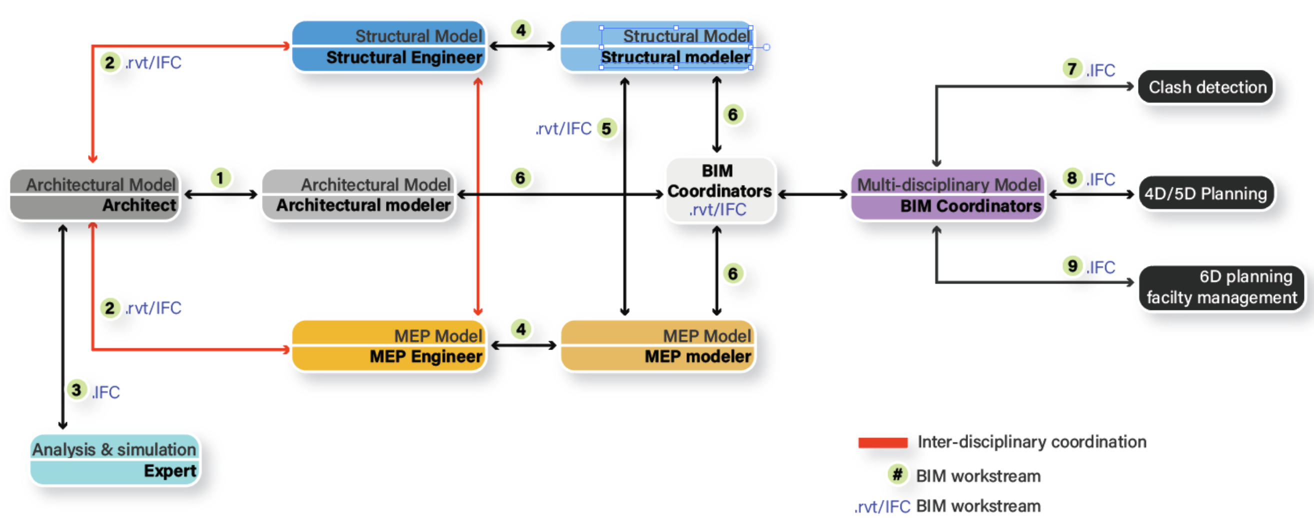

Figure 66 Simplified version of the workflow and communication diagram

The BIM coordination layer for each design task team has defined steps for how each model gets checked and verified by the BIM manager or coordinator before it gets shared by the entire project team. This process ensures that any conflicts or errors in the models are identified and resolved before they impact the construction phase. The BIM manager or coordinator carefully reviews the models for accuracy, completeness, and adherence in accordance to the model execution table. Once the models pass the verification process, they are then shared with the project team, allowing for seamless collaboration and coordination throughout the design and construction process.

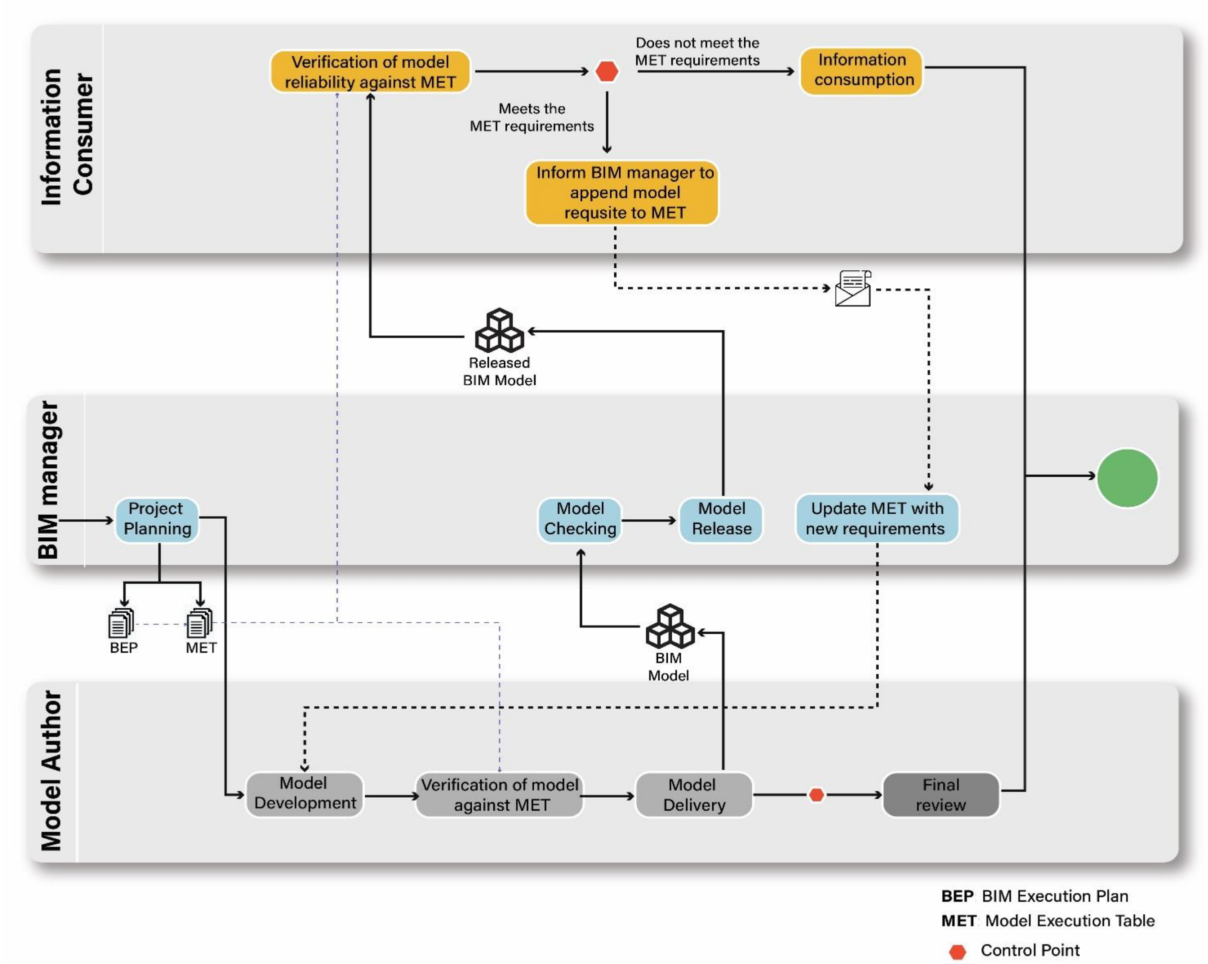

Figure 67 Extended version of the coordination layer for BIM Design workflow model

BIM design flow in regards to model authoring unfolds in three distinct stages, each marked by increasing levels of integration and cooperation among design teams. As a design passes through these stages, it grows in complexity and detail. At the same time, the level of collaboration will increase across the different disciplines in the design task team, ultimately resulting in a fully coordinated and detailed virtual representation of the project (Succar, 2009).

- **Models at Stage 1** involves of object-based modeling in a 3D parametric software tool like ArchiCAD, Revit, Digital Project, and Tekla. Task teams generate single-disciplinary models within their preferred modeling software (Francois Levy, 2019). These models include architectural design models, structural models, and MEP models. Collaborative practices at Stage 1 are limited, with no significant model-based interchanges between different disciplines. However, object-based models and the desire for an early and detailed modeling of assets matter to encourage fast-tracking of the design phases.
- **Models at Stage 2** involves collaboration with diverse participants, allowing the exchange of models in proprietary or non-proprietary formats. It emphasizes clash detection and coordination meetings to resolve conflicts between models. Clear communication channels and protocols are established to ensure effective collaboration (Francois Levy, 2019). The goal is to achieve a fully coordinated and integrated model that accurately reflects design intent and facilitates subsequent stages. This preliminary model integration fosters cross-disciplinary learning and enhances understanding of complex systems, paving the way for more sophisticated advancements in later stages.
- **Models at Stage 3** involves network-based integration of semantically-rich models across disciplines for a holistic view of the project. This integration is facilitated by model server technologies, federated databases, or cloud solutions. BIM Stage 3 models enable complex analyses, 4D to 7D planning, and simulations, allowing stakeholders to visualize construction processes, identify clashes, optimize scheduling, and estimate costs accurately (Francois Levy, 2019). Additionally, these models support efficient facility management with real-time data on energy consumption, maintenance needs, and sustainability.

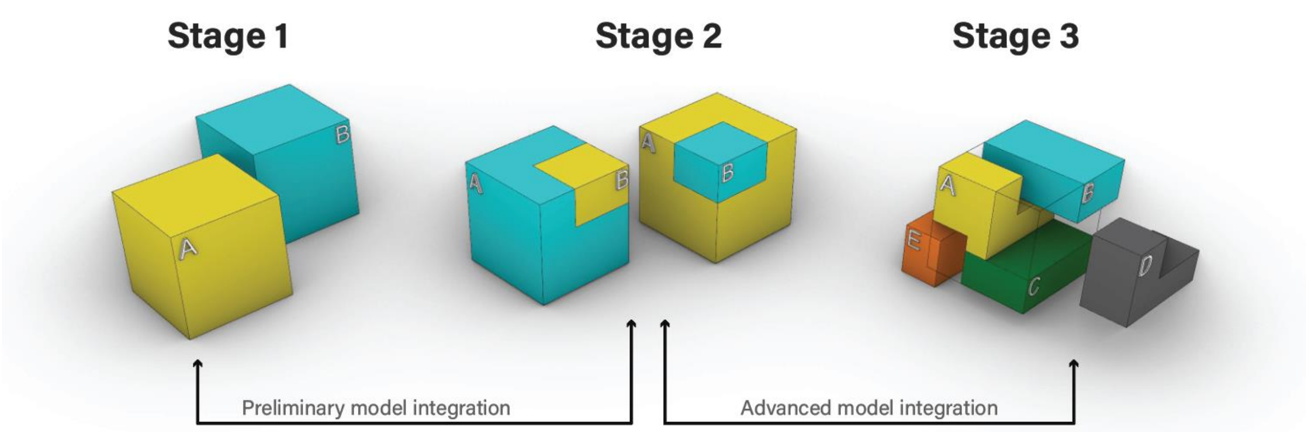

Figure 68 Illustration of Model integration stages

The exchange and level of detail is governed by the model execution table (MET). The MET will track the level of detail of each model while being shared amongst professions. This ensures that everyone involved in the project, regardless of their profession, is aware of the specific level of detail each model contains (Francois Levy, 2019). The MET also serves as a reference point to avoid miscommunication or confusion regarding the information shared (Bimal Kumar, 2019). By maintaining consistency in the level of detail, the project can progress smoothly and efficiently, with all team members working towards a common understanding of the models being utilized.

Multi-User Collaboration: BIM software with multi-user collaboration capabilities enables multiple users to access and edit the same BIM model simultaneously, including architects, engineers, contractors, and other stakeholders. This differs from traditional software where only one person can edit a file at a time, allowing for more efficient and collaborative project management. (AUTODESK, 2023)

Collaborative BIM software aids in conflict resolution by detecting real-time conflicts between structural elements and electrical systems. This helps teams identify and resolve issues before they escalate into construction problems (AUTODESK, 2023). Cross-disciplinary coordination is also enhanced by BIM software, as different teams are responsible for interconnected aspects like structural element location and electrical and plumbing system routing. This enhances coordination, reducing the risk of conflicts and rework. Changes made by one user are immediately reflected in the shared model that others are working on. This ensures that everyone has access to the most current version of the model and can see updates as they happen.

Collaborative BIM platforms typically have role-based access controls. This means that users have different levels of access and permissions within the model based on their roles and responsibilities in the project (Ingram, 2020). Many collaborative BIM tools are cloud-based or server-based, allowing users to access and work on the model from anywhere with an internet connection or local area network.

Collaborative BIM platforms often include version control mechanisms to track changes and revisions over time. This helps maintain a history of the model's development and allows users to review and roll back to previous versions if needed. (Bimal Kumar, 2019) Additionally, multi-user collaboration reduces the risk of errors or inconsistencies, as all changes are synchronized and visible to everyone working on the model. (Ingram, 2020) Some BIM software includes built-in communication tools like chat, commenting, or annotation features directly within the model (Bimal Kumar, 2019). This enhances communication among team members, allowing them to discuss issues, ask questions, and provide feedback in context.

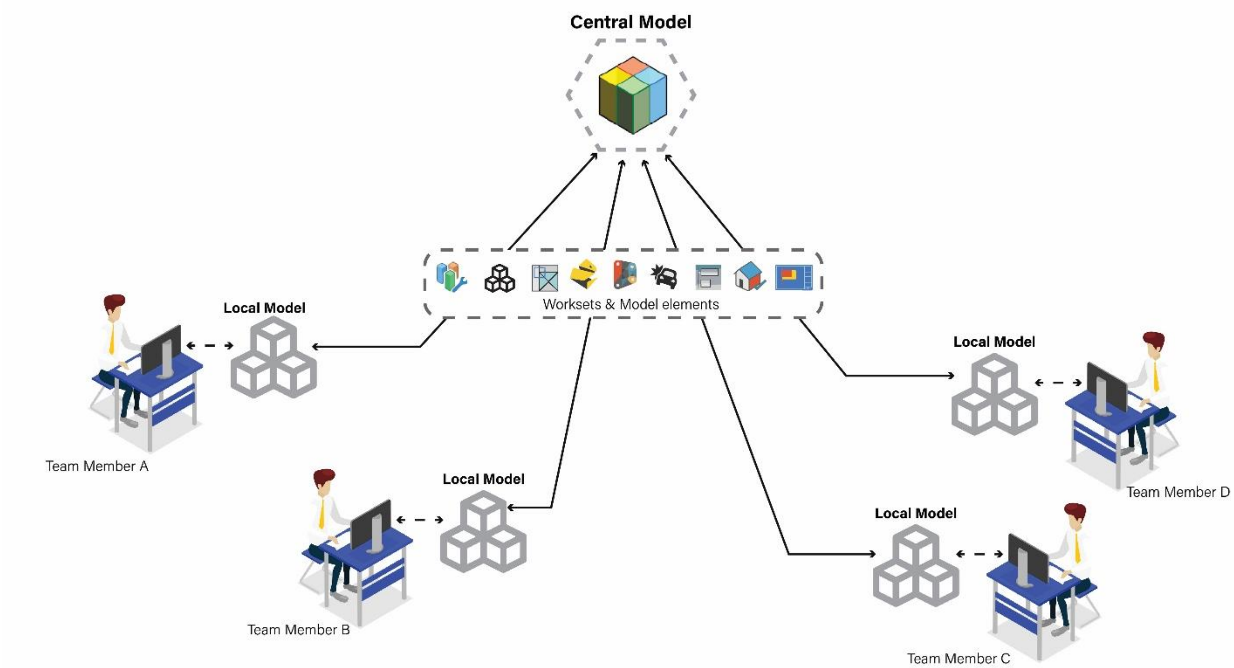

Figure 69 Simultaneous Access/ Concurrent work-sharing Model

5.4.4 BIM implementation summary

A comprehensive BIM implementation system, consisting of the BIM Technological Framework, Information Requirements Framework, and BIM Design Workflow, is essential for the relatively successful implementation of the BIM process in a project. The three main pillars covered here are crucial components that work together to ensure the smooth integration and utilization of BIM in all stages of the project. The range of implementation may vary from project to project and according to the client's needs and requirements, but the overall goal remains the same - to improve communication, collaboration, and efficiency in the design process.

By establishing a well-defined workflow, project teams can effectively streamline the exchange of information and ensure that all stakeholders are on the same page. This includes defining roles and responsibilities, establishing clear communication channels, and implementing standardized processes and protocols. With a solid workflow in place, project teams can minimize errors, reduce rework, and ultimately deliver a higher quality end product. Additionally, a well-structured workflow allows for better coordination and collaboration among multidisciplinary teams, enabling them to work together seamlessly towards a common goal.

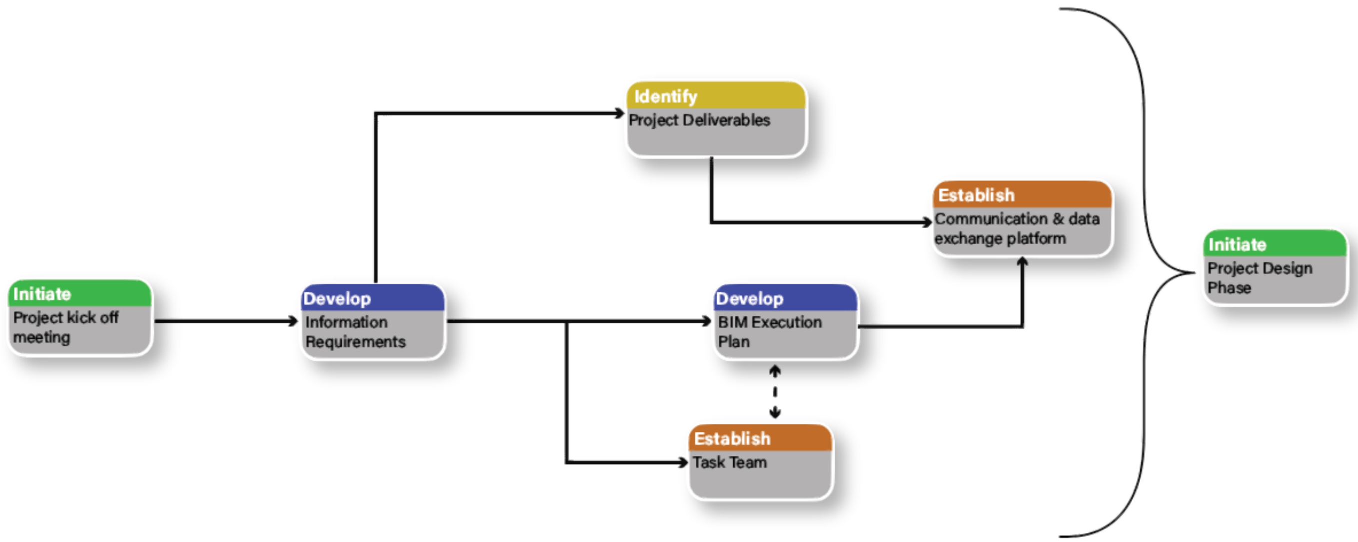

Figure 70 An oversimplified version of a Predesign BIM implementation core steps

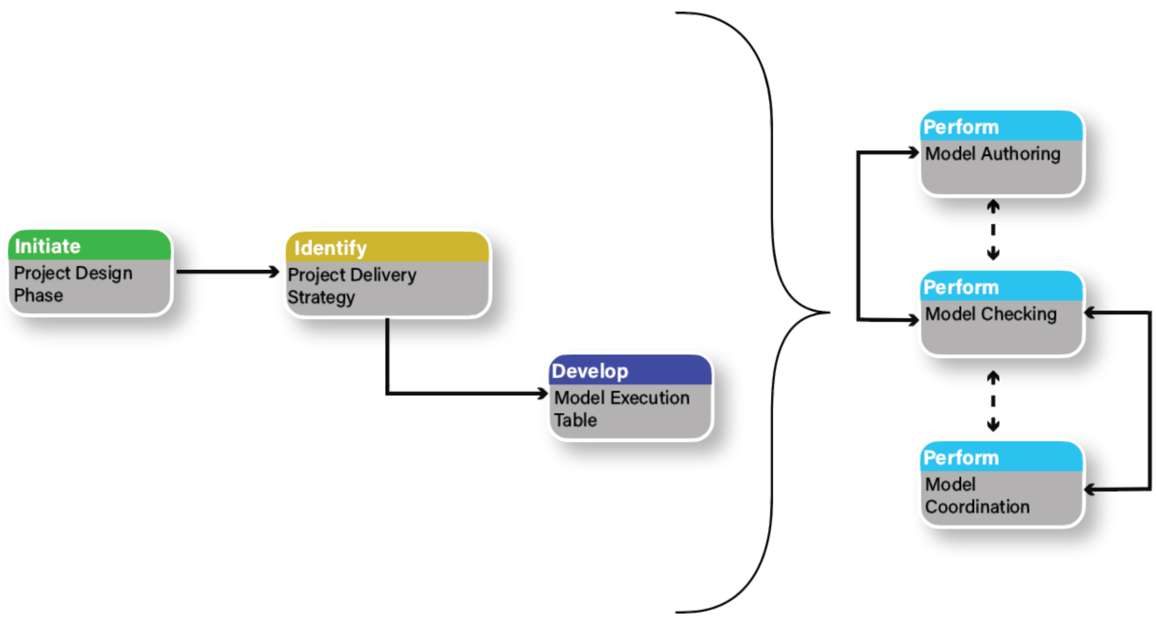

Figure 71 An oversimplified version of a Design phase BIM implementation core steps

By continuously developing the implementation process and iterating on each aspect of the three main pillars, a continuous development of the BIM workflow can be achieved. This continuous development ensures that the workflow remains efficient and up-to-date with the latest industry standards and technological advancements. By regularly evaluating and improving the workflow, project teams can adapt to changing project requirements and deliver better results. Ultimately, a well-developed BIM workflow can contribute to the overall success of a project and the satisfaction of all stakeholders involved.

Chapter 6 - Conclusion and Recommendation

6.1 Conclusion

In the dynamic landscape of modern construction and design, the comparison between conventional and Building Information Modeling (BIM) workflows has become increasingly pertinent. This exploration is rooted in a project where both approaches were simultaneously deployed, presenting a unique opportunity to dissect the nuances of their performance. Notably, these projects shared a common challenge—limited time constraints. While the conventional design process managed to maintain synchrony with the BIM project's timeline, it became evident that this alignment, rather paradoxically, resulted in several omissions and errors within the BIM project. This dichotomy serves as a compelling entry point into the broader discourse surrounding BIM implementation, shedding light on the prerequisites, challenges, and intricacies of harnessing BIM's transformative potential in the AEC industry.

In the comparison of the conversational and BIM workflows in the project, it becomes evident that both projects ran concurrently and encountered similar challenges, primarily related to time constraints. Remarkably, the conventional design project managed to keep pace with the BIM project in terms of timelines. However, this alignment in timelines led to several omissions and errors within the BIM project. This illustrates a crucial point: the effectiveness of BIM implementation hinges on having the appropriate resources and planning in place.

BIM implementation is not a straightforward endeavor; it demands proper planning and thorough preparation. The reason lies in the intricate and complex nature of BIM systems, where even minor oversights can have substantial repercussions. While BIM is often heralded as the panacea for the construction industry's challenges, a rushed or poorly understood implementation can introduce serious issues that hinder the design process and the project as a whole.

To unlock the full potential of BIM, a tailored approach is essential. Project-specific factors such as scope, complexity, budget, and integration capabilities must be taken into account. Leveraging open BIM standards and collaborative platforms is not just beneficial but crucial. Furthermore, the establishment of clear roles and responsibilities is pivotal for fostering effective collaboration among stakeholders. Regular meetings become the linchpin in enhancing interdisciplinary cooperation. In addition to these considerations, the contextualization of BIM implementation should factor in variables like location, cost, expertise, and client expectations. Robust personnel training and a commitment to continuous monitoring and improvement form the cornerstone of this process.

It is important to note that the BIM design process typically demands more time and resources compared to conventional methods of building design. Yet, the benefits it brings to the table are substantial, including improved coordination among stakeholders and significant reductions in errors during the design and construction phases. In essence, it is an investment that pays dividends in terms of efficiency and quality.

However, achieving success in BIM implementation is not solely a technical matter. Various aspects of BIM integration should be addressed right from the contractual negotiation stages. To ensure this, organizations should consider involving BIM personnel in the negotiation process or providing thorough training to the contract administration team regarding the intricacies of a BIM project. This proactive approach serves a dual purpose: it sets the stage for a successful BIM implementation, optimizing its potential benefits, and simultaneously mitigates potential risks and challenges.

The comparison of conventional and BIM workflows in this project highlights the critical importance of well-planned BIM implementation. It reinforces the idea that BIM, when approached with the appropriate resources, meticulous planning, and a tailored strategy, can be a game-changer for the construction industry. However, this transformational potential can only be fully realized when all facets of BIM integration are considered, from project-specific adaptations to proactive contractual negotiations, ensuring that the promise of BIM as a transformative force in construction becomes a reality.

6.2 Recommendation

In pursuit of heightened efficiency and effectiveness in project delivery, ECDSWC is eager to glean insights from past experiences, particularly those acquired from the CoESCoEM project. The overarching objective is to methodically incorporate Building Information Modeling (BIM) into forthcoming projects. However, this transition presented a multifaceted challenge, highlighting the need for further research and understanding in BIM implementation across different projects and throughout the entire lifecycle of a building.

One of the foremost obstacles identified in the implementation of BIM is the initial investment. It is crucial to recognize that BIM is not a universal panacea for all project types. To surmount this financial hurdle, ECDSWC commits to an in-depth analysis of various project attributes when determining the suitability of BIM implementation. This discerning approach ensures that resources are allocated judiciously and effectively, underscoring the need for ongoing research into cost-benefit analyses across different project types.

The foundational tenets of BIM, including improved communication channels, enhanced coordination mechanisms, and robust data management systems, hold the potential to seamlessly integrate with conventional design methodologies. By infusing these elements, ECDSWC aims to bolster the efficacy of their existing systems. Nevertheless, it's vital to acknowledge that the resource allocation and effort required for a BIM-driven design process markedly differ from those of traditional methods. Consequently, when crafting contracts and engaging in negotiations, the organization must factor in the additional demands that the BIM framework necessitates, emphasizing the need for further research into contractual and negotiation strategies specific to BIM projects.

Notably, the ECDSWC team, while brimming with potential, is relatively inexperienced in the realm of BIM. Consequently, a dedicated commitment to consistent training, resource provisioning, and expert guidance is indispensable to harness their latent capabilities and propel them toward proficiency, highlighting the ongoing need for education and expertise in BIM across the workforce. The cornerstone of a successful BIM implementation lies in a comprehensive system that encompasses the BIM Technological Framework, Information Requirements Framework, and BIM Design Workflow. This holistic approach is paramount for fostering collaboration, ensuring efficient data management, and encouraging interdisciplinary cooperation. It is imperative that this system be tailored meticulously to align with the specific project's scope, complexity, user needs, budgetary constraints, and integration capabilities, emphasizing the need for research and development in customizing BIM methodologies for different projects.

Facilitating an efficient data exchange framework, grounded in open BIM standards and collaborative platforms, empowers task teams and individual team members to communicate seamlessly. This streamlines processes, ultimately yielding successful project outcomes. A well-defined BIM design workflow replete with clear roles and responsibilities forms the bedrock of effective collaboration. Regular communication and coordination meetings are essential forums for addressing issues, cultivating interdisciplinary cooperation, and optimizing workflows, underscoring the need for standardized best practices and communication protocols in BIM.

Crucially, the implementation of BIM should not be approached as a one-size-fits-all solution. Instead, it should be customized to align with the distinctive needs of each project and the overarching goals of the organization. Factors such as geographical location, project cost, timeline, existing BIM expertise, resource availability, and client expectations must be meticulously considered in this contextualization process, calling for continuous research into tailoring BIM to specific project requirements.

Ensuring a stable BIM implementation necessitates the involvement of all relevant personnel within the organization in tailored BIM training programs. Adequate support must be provided to equip every team member with the requisite skills and knowledge. Ongoing monitoring and evaluation mechanisms are invaluable tools for pinpointing areas of improvement and for making necessary adjustments to the BIM implementation process, thus ensuring its continued success, emphasizing the need for ongoing training and assessment in BIM adoption.

ECDSWC's journey toward enhancing project efficiency and effectiveness through BIM implementation shall be marked by a commitment to strategic analysis, investment, tailored systems, comprehensive training, vigilant monitoring, and continuously developing the implementation process. This multifaceted approach will aid the organization's dedication to leveraging BIM's potential while mitigating the challenges inherent in its implementation, highlighting the importance of an ongoing commitment to research, adaptability, and education in the realm of BIM.

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Annexes - Research instruments

Questionnaire for the BIM design team

What was your role in the project?

11 responses

Designer

BIM MODELLER/DESIGNER

BiM Architect

Bim Modeler / Coordinator

modeler

Design team member

Design and modeling

Beam Modeling/ Designer

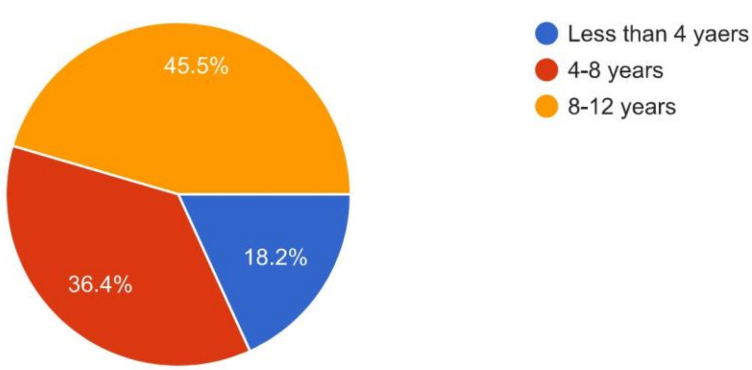
SANITARY DESIGN

Structural design and BIM modeler

Project Manager

How many years of work experience do you have? Copy

11 responses



What was your role in the project?

11 responses

Designer

BIM MODELLER/DESIGNER

BiM Architect

Bim Modeler / Coordinator

modeler

Design team member

Design and modeling

Beam Modeling/ Designer

SANITARY DESIGN

Structural design and BIM modeler

Project Manager

How many years of work experience do you have?

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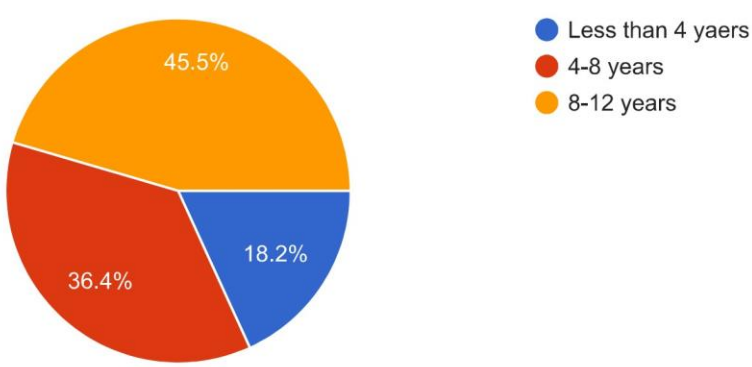
11 responses



Do you have any prior experience working with BIM?

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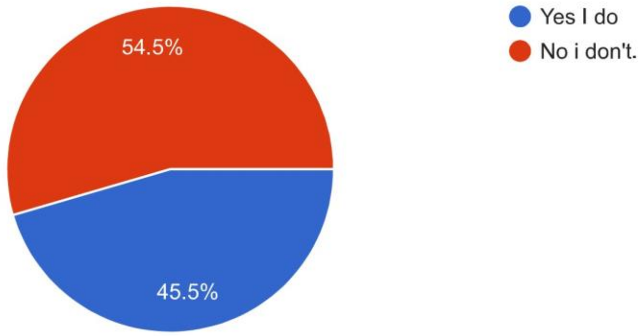
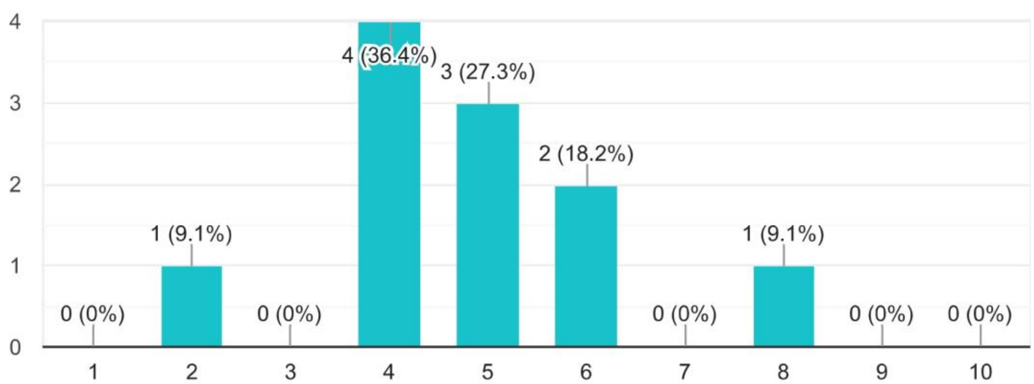
11 responses



What was your level of understanding regarding the project beforehand?

Copy

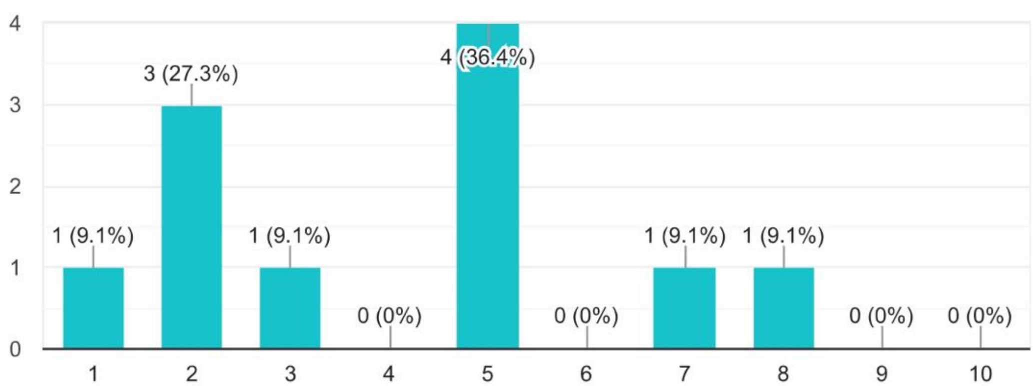
11 responses

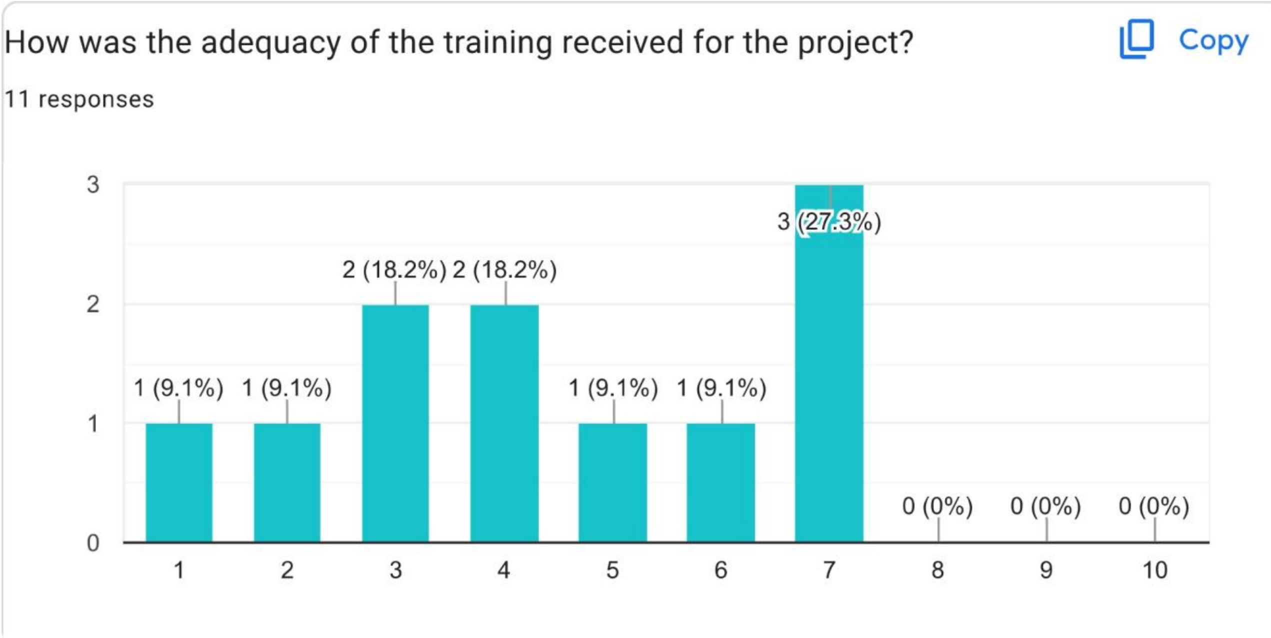


What would you say your level of understanding of the BIM process was at the beginning of the project?

Copy

11 responses




How was the adequacy of the training received for the project?
Copy
11 responses
1 (9.1%)
1 (9.1%)
2 (18.2%)
2 (18.2%)
1 (9.1%)
1 (9.1%)
3 (27.3%)
0 (0%)
0 (0%)
0 (0%)
0
1
2
3
1
2
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4
5
6
7
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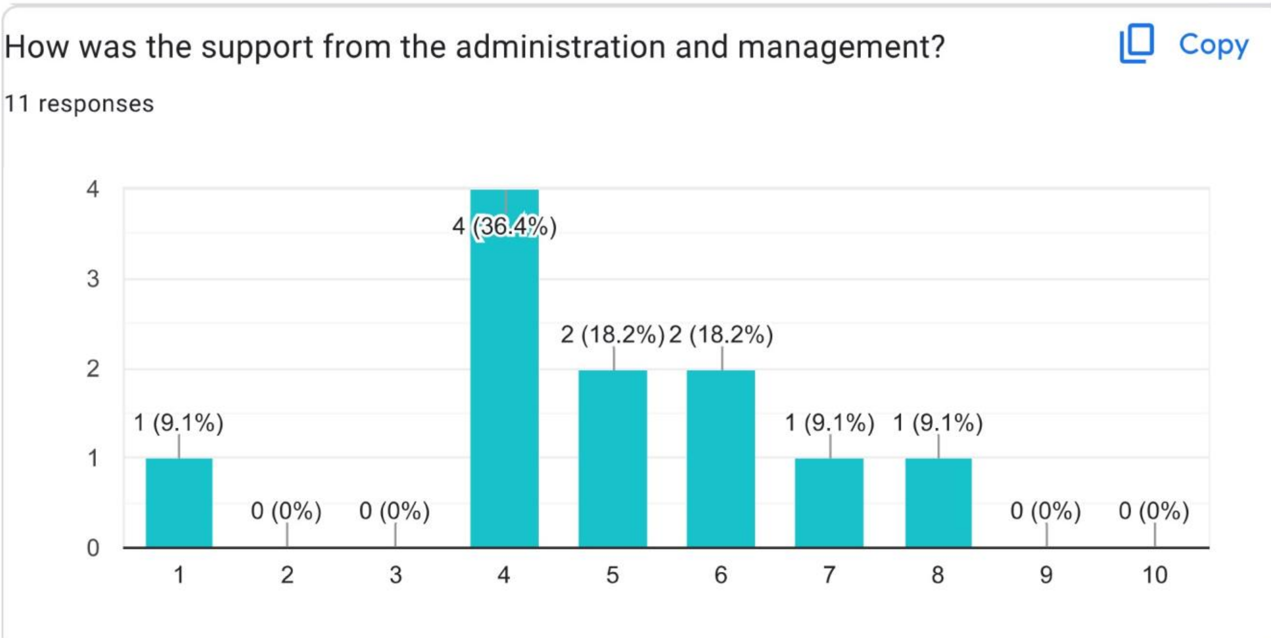
9
10


How was the support from the administration and management?
Copy
11 responses
1 (9.1%)
0 (0%)
0 (0%)
4 (36.4%)
2 (18.2%)
2 (18.2%)
1 (9.1%)
1 (9.1%)
0 (0%)
0 (0%)
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10

The experience of switching from traditional workflow to BIM workflow?

9 responses

It seems a good progress in getting a real project design.

it is not easy. ......

Strenuous

Quite challenging

It is a good experience

difficult due too much pug in to feed in

IT IS TIME TAKING FOR THE FIRST TIME

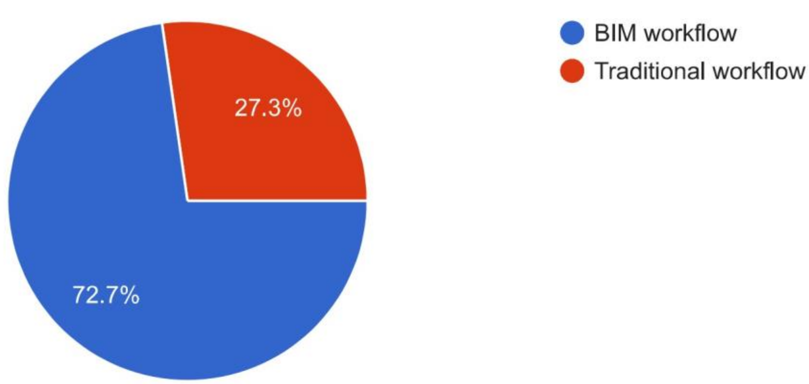
1 year

Good

Which design process do you prefer professionally?

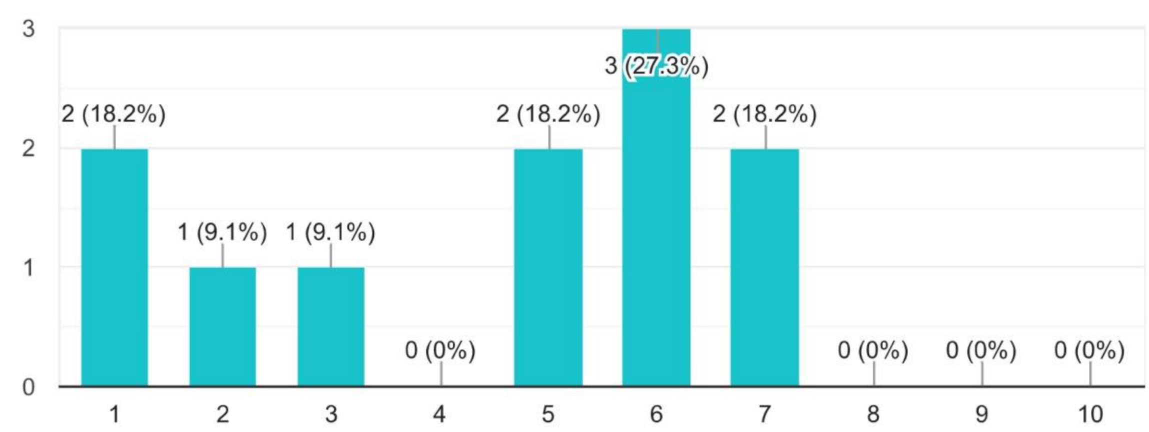
Copy

11 responses



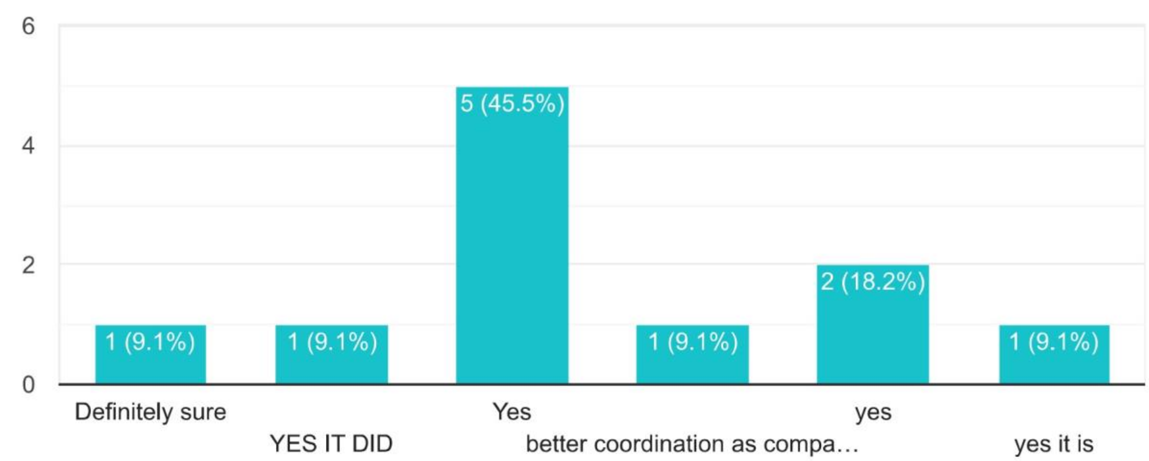
What kind of resources (resources such as reference materials and expert guidance,) did you have while executing the project?

11 responses



Did BIM help you collaborate with other team members? Did it improve communication and coordination?

11 responses



How was the coordination with other non-BIM aspects of the project or people?

10 responses

Great but a lot more to be done

very difficult.... not easy to communicate easily.....

Not satisfied cause of the platform that we was working on

Poor

Good

There is a platform for coordination like jury and presentations which is not enough but Mostly it depends on the professional carefulness for detail and final output.

Through verbal communication

IT IS GOOD

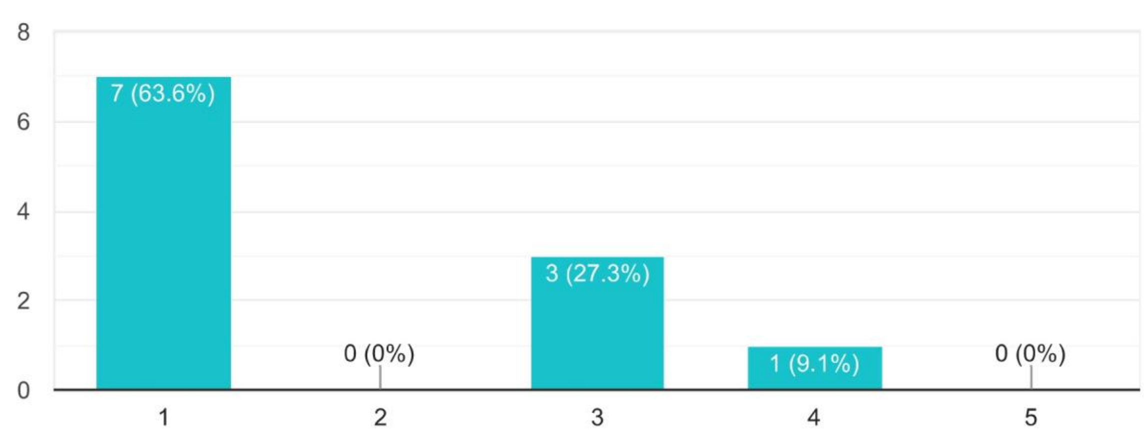
It's some how difficult and a challenge because of the details and information that the BIM work flow needs

Convectional way

Was the time allocated for the project enough to get the desired output?

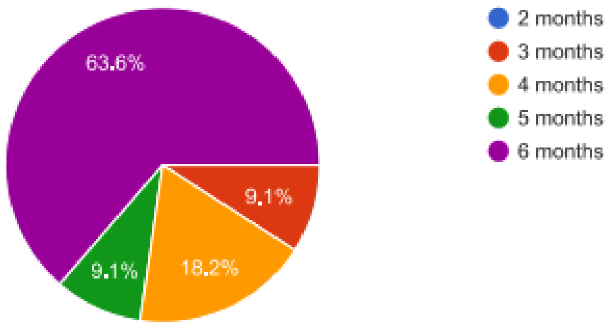
Copy

11 responses



For these kinds of projects, what should be an appropriate time to sufficiently execute the design using the BIM design workflow?

11 responses



What types of barriers did you encounter while implementing BIM?

11 responses

Inadequacy of full Implementation of the training to the work environment

lack of software, Lacke of trainers, inadequate time....

Tools like Software

Lack of mentorsship

structural section detailing

Softwares

Low familiarity with the software and way of implications from those who have the experience.

Electrical symbol Template and feed in for analysis

WE DDINT HAVE ANY PORSONE TO ASKE W@ WE WILL DO INCOUNTER THE PROBLEM

1. Model management with others disciplines can due to the the lack of responsibility matrix 2. Due to the lack of third party software availability it creates manual manipulation of analysis collaboration with the BIM software 3. Team development for detailing it needs 4. Due to lack of understanding in quality team it leads to conventional approach to approve the design

Awareness of people

How did this BIM experience help or aid you in your professional life or career?

10 responses

I am at the begining for the future I have a plan to implement it in various parts of my profession

just the flow of work is clear, visualization is increase......

Better understanding of the construction workflow between the digital creations and onsite project execution

Understanding of digital construction

40%

It help me to give more attention to detail and that i need to know construction techniques.

Improve site obstacle problem

IT HELPS TO SEE THE FUTHER

It helps to review all details as per the code and standards and us aware of to don't by pass each and every detail

Quality of project

What were some of the most important features of the BIM software that you felt had a significant effect on your workflow?

9 responses

I have got an understanding of getting a centralized model where by each level of development shall be acessed

3d visualization, work flow....

Dynamo for Revit

Level of details

Collaboration and clashes detection

Electrical symbol Template and feed in for analysis

THE ANALISIS PART

Details preparation and documentation presentation make's it tedious work for the engineers

Autodesk BIM and its plugin

What was the process for creating and managing BIM models? Were there any specific tools or techniques that were particularly helpful?

9 responses

In creating BIM model of sanitary system I get use of templates and to date design objects & that was helpful

Autodesk suits

Sustainability factors

Information

No that I know of

tutorial videos'

N/A

Other third party plugins and software's makes very like CSIX Revit and Graitech power pack and BIM studio

Autodesk Navis work software helps to manage BIM models

What would you do differently if you were to work with BIM again? Are there any changes you would personally make to make your work more efficient?

8 responses

I would have added additional BIM objects to the template

Approach Generative design methodology

Software's to learn

Try to create a clean model to reduce Rework.

yes, I will improve speed to deliver in short period of time

IT THAIR ARE ALOT OFF THINGS THAT WE DONT DO AGEN FOR THE NEXT PROJECT

Using and enhance our understanding behind the Dynamo and the plug-ins listed above

Yes

Any other things you may want to add.

6 responses

No

Option 1

Knowledge sharing is very important form others who have been working with BIM other than starting from scratch.

N/A

Create detail BIM execution plan and working according to the execution plan make it more productive last but not least creating standards according to ISO for the other professionals like for contact administration quality teams management teams makes it easy for improving our deliverables. Generating our office material specifications and also characterization and level of details for documentation in the form of design guideline template

Questionnaire for the management team

BIM Implimentaion on the project Center of Excellence for Sustainable Construction Engineering and Management (CoESCoEM) Administration Building.

4 responses

Publish analytics

Describe your role at ECDSWC.

4 responses

Building works executive officer

DCEO

design sub process manager

BIM Manager

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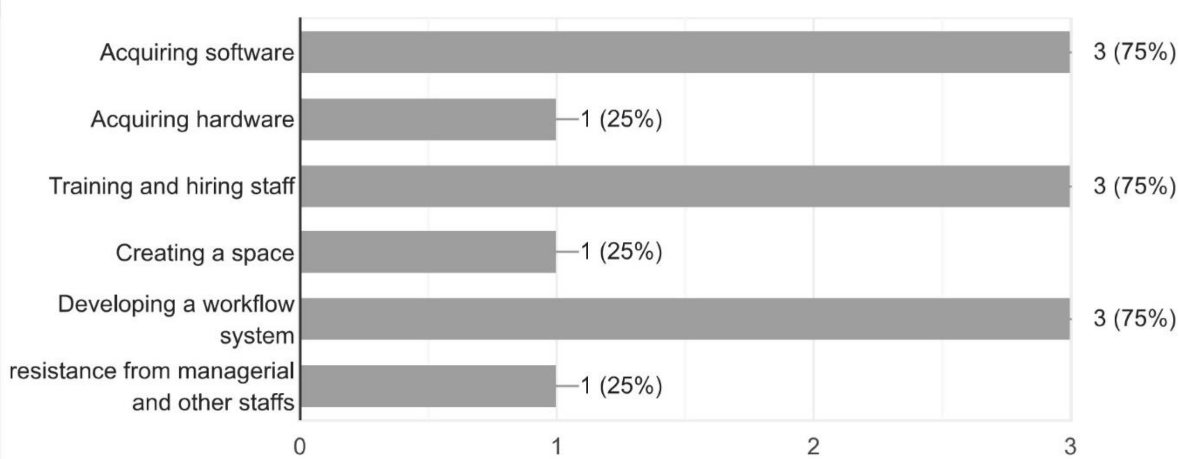
What where the main challenges while first implementing BIM on the project? (can check multiple boxes)

4 responses



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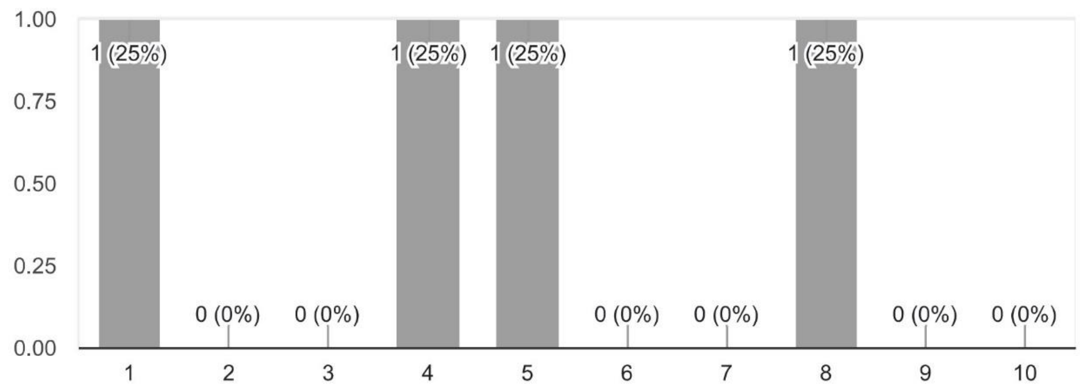
What was your level understanding of the BIM prior to the project.

4 responses



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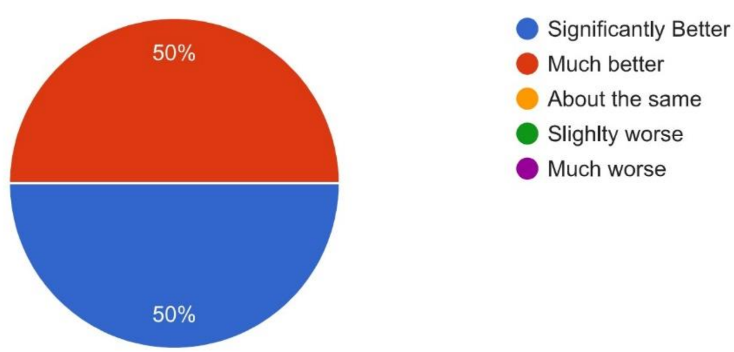
In your opinion how does the BIM workflow and output compare to the traditional workflow?

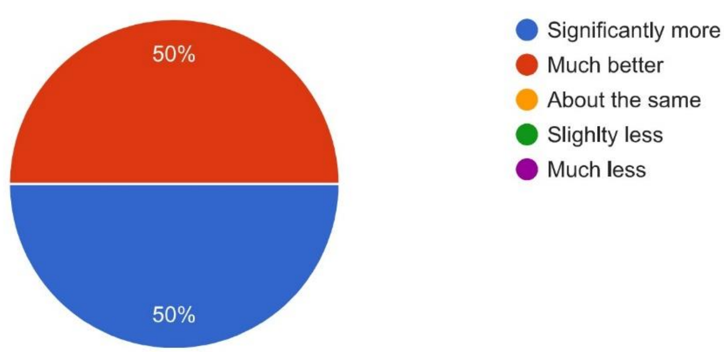
4 responses



What is the work load of BIM compaired to the traditional method, in your opnion?

Copy

4 responses



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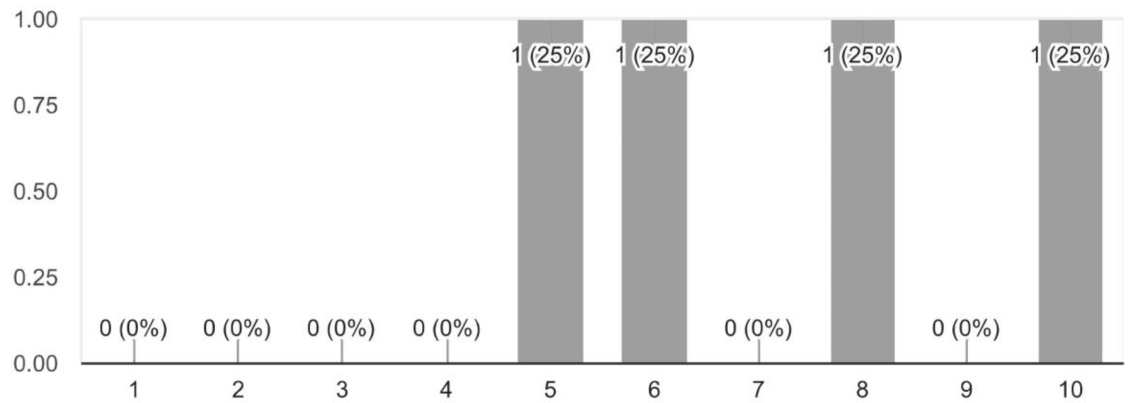
How would your rate your performance, engagement and input in the project?

4 responses



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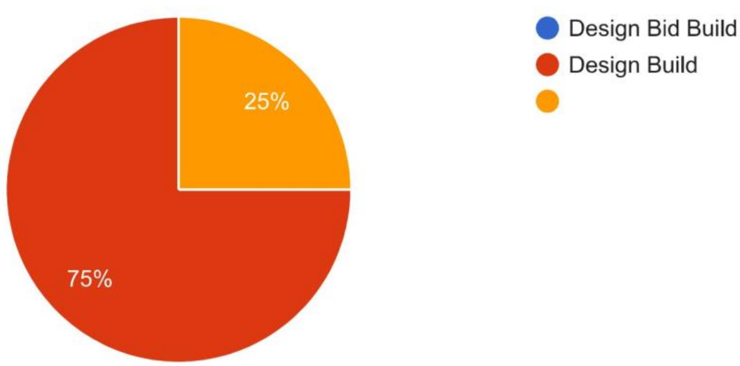
In your opinion which building procurement method is better integrated with BIM?

4 responses



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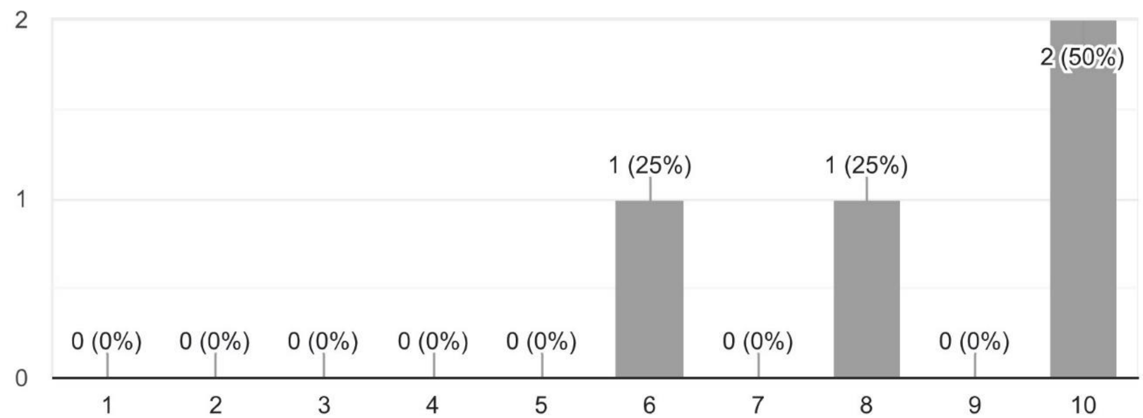
How would you rate the performance of the BIM team's performance on the project.

4 responses



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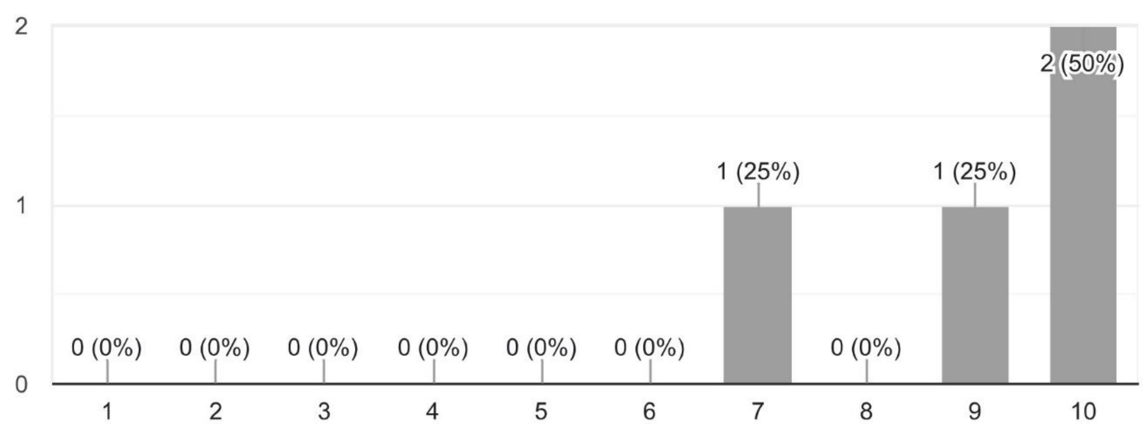
In your opinion is further education and training for the current team is necessary?

4 responses



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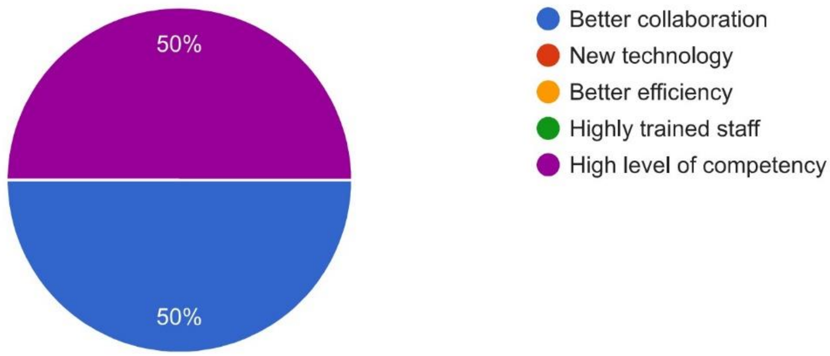
In your opinion what would be the most significant contribution of BIM at the company?

4 responses



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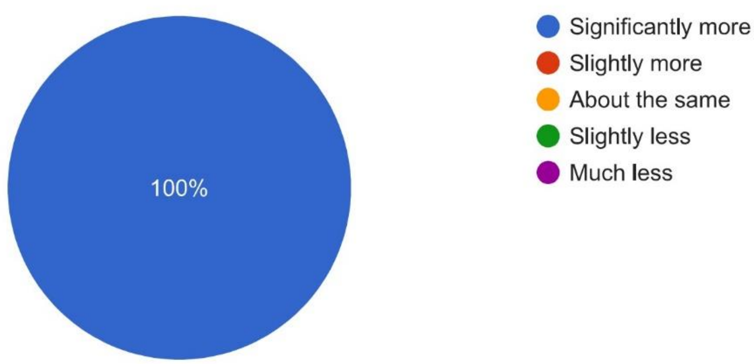
In your opinion should be the BIM design workflow design fee compared to the traditional design work flow?

4 responses



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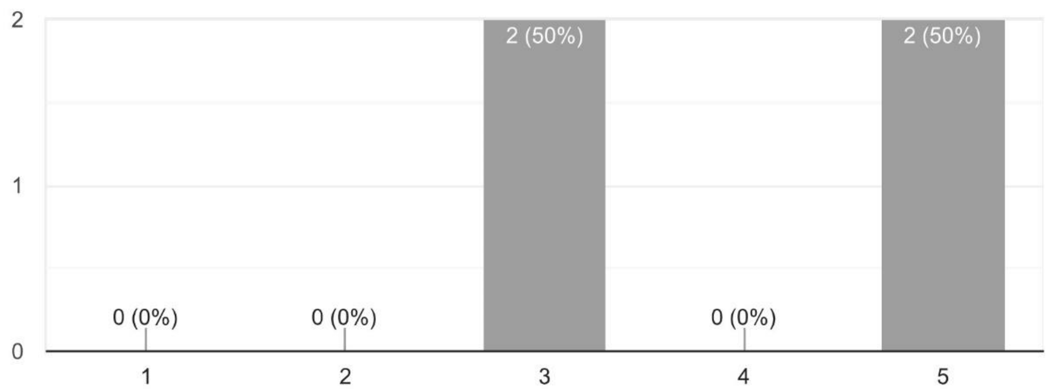
In your opinion is the BIM workflow easily integrated with other companies workflow such as quality check, PPM and urban design and planning?

4 responses



What tools and resources do you plan to invest and support the implementation of BIM in future projects?

4 responses

Training packages, more PC, server. . .

We have to establish further included on corporations (each professionals have named by BIM structure Such as BIM architect, BIM modeler...,,

training,infrastructure provission

COBie,Classification, addins and extensions and additional workflow.

Anything further you would like to add.

2 responses

Need a lot of logistics (higher performance computer, server, attractive salary , continuous training

nothing