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Collaboration in the AEC Industry and the Role of Building Information Modeling in Optimizing it

Case Study of the Yuan Ding School Extension

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Abstract

Collaboration is an essential factor to success in the Architecture, Engineering, and Construction (AEC) industry. As projects become increasingly complex, involving diverse stakeholders and multidisciplinary teams, effective collaboration becomes crucial for maintaining clear information flow, timely decision-making, and efficient execution. Yet, the industry often faces challenges like fragmented workflows, miscommunication, and inconsistent data management which disrupt project success and efficiency.

This thesis begins by analyzing the critical role of collaboration in the AEC industry, focusing on the challenges posed by complex projects and diverse stakeholders. It highlights the impact of information mismanagement and fragmented workflows on project efficiency, especially in international collaborations. These insights stem from the authors' complementary internship experiences: one author gained exposure to the challenges of project coordination and interdisciplinary collaboration, while the other focused on the practical application of BIM for improving overall efficiency. Together, these observations formed the thesis's focus on enhancing collaboration through BIM-based solutions.

The study explores traditional collaboration practices and examines the limitations of 2D CAD workflows in modern AEC projects, identifying challenges such as communication inefficiencies, data fragmentation, and time-intensive processes, aggravated by the lack of real-time collaboration across disciplines. By highlighting these gaps, the thesis investigates how BIM facilitates real-time collaboration, centralized data management, and seamless interdisciplinary workflows, offering solutions to these inefficiencies. It emphasizes the role of BIM tools, cloud platforms, and standards in fostering interoperability, improving data sharing, and reducing rework, while also exploring advanced dimensions of BIM, including 4D (time simulation) and 5D (cost estimation), for their practical applications in optimizing project management and enhancing outcomes.

This research incorporates the case study of the Yuan Ding Middle School extension, which serves as an ideal example of international collaboration among multiple firms and partially demonstrates the proposed workflow in action, highlighting the opportunities of applying BIM-based methodologies. Despite certain constraints and limitations as students conducting this research, such as restricted access to software licenses, the case study showcases the modeling process in Revit, creating a detailed and information-rich BIM model. This model, while adaptable for various purposes, was utilized for 4D scheduling and 5D cost analysis partially in Navisworks, with integration from other software. The findings underline BIM's potential to streamline workflows, improve project efficiency, and add value across various project phases, even in the context of limited resources. The thesis concludes by emphasizing the need for broader BIM adoption to address inefficiencies and foster enhanced collaboration in the AEC industry, arguing that despite challenges like technological adaptation and training, BIM provides a transformative framework for improving project outcomes.

Keywords: Building Information Modeling (BIM), AEC Industry Collaboration, BIM-based Workflow, Workflow Optimization, Collaborative Workflow

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Chapter 1

1. The Role of Collaboration in the AEC Industry

1.1 Introduction

The concept of building design and construction has evolved from being a single-person activity, often associated with the "master builder" (Larsen and Tyas, 2003), to a collaborative, multi-person activity , while adding complexity to the design process (Muthumanickam N.K. et al., 2023). Many studies indicate this increase in complexity of AEC industry projects. Clough et al. (2008) determines this complexity due to the involvement of various stakeholders such as financing bodies, authorities, architects, engineers, lawyers, contractors, suppliers, and trades. Bimal Kumar (2015) indicates this complexity based on the enormous flows of information and believes that the most major problems of this industry stem from the highly complex and unstructured nature of information flows and exchanges in a typical construction project. Other studies focus more on the design phase, for instance (Gero, 1990) compares the building design phase with aerospace and systems engineering and believes that similar to aerospace and systems engineering the building design process is neither a sequential process nor a single person activity; rather, it is a collaborative process where multidisciplinary design agents enter and exit across multiple phases. Another study refers to the building design phase as an iterative trial-and error process that typically starts with hand-drawn sketches, slowly evolving into abstractly specified 3D models as designers get more information and refine their idea. (Mills, 2011)

Based on this information and various studies, it is understandable that Collaboration is fundamental to the architecture, engineering, and construction (AEC) industry due to its inherently complex, project-based nature. Unlike many other industries, AEC projects rely on temporary partnerships between diverse stakeholders, including architects, engineers, contractors, suppliers, and clients, who must align their efforts to achieve shared objectives within specific timeframes and budgets (Winch, 1989). The transient structure of these collaborations often results in inefficiencies, as the relationships built and knowledge gained during one project may not carry over to the next (Dubois and Gadde, 2002, as cited in, Cao et al., 2018). This fragmentation, coupled with the industry's reliance on bespoke project teams, challenges the establishment of long-term collaboration networks and standardized practices (Ling et al., 2014).

Despite these structural challenges, effective collaboration in AEC projects has a significant influence on project success. Collaborative ties not only improve design and construction outcomes on individual projects but also contribute to the development of broader relationship networks that enhance the industry's ability to acquire and share knowledge over time (Cao et al., 2018). This is particularly important in large, complex projects, where the interdependencies between stakeholders—ranging from financing bodies to trade professionals—necessitate trust, coordination, and the seamless exchange of information to mitigate risks and address uncertainties (Kadefors, 2004; Maurer, 2010). However, the lack of a holistic approach to project lifecycles and limited stakeholder involvement in early stages often result in inefficiencies and prevent the realization of the full benefits of collaboration (Crotty, 2012).

The challenges of collaboration are magnified in international construction projects, where cultural, political, and economic differences add layers of complexity. In such contexts, partnerships are critical for addressing regional risks and uncertainties, as well as for sharing resources and knowledge across firms (Park et al., 2011). Studies have shown that collaborative practices, including project partnerships, subcontractor selection, and joint decision-making, are key strategies for reducing risks and enhancing project performance (Dimitros, 2010; Ozorhon et al., 2010). These dynamics underscore the importance of fostering robust, adaptable collaboration mechanisms that accommodate the unique demands of both domestic and international AEC projects (Chan & Tse, 2003; Sridharan, 1997).

1.2 Information Flow in AEC Collaboration

A critical aspect of successful collaboration in AEC projects is the effective flow of information among stakeholders. Poor information management and miscommunication can lead to costly mistakes, delays, and project failures (Crotty, 2012). In the fragmented nature of the AEC industry, where project-specific teams are assembled for each project, information is often shared inefficiently, creating barriers that slow down decision-making processes and hinder the resolution of issues in a timely manner (Latham, 1994; Egan, 1998). This lack of seamless communication across different stages of the project lifecycle can result in design, construction, and operational challenges that escalate costs and extend timelines.

Effective information management is vital in mitigating these risks. It ensures that all stakeholders have access to up-to-date, accurate information, enabling them to make informed decisions and adjust plans as necessary. Studies have shown that when information is exchanged properly, the risk of errors and misunderstandings decreases significantly (Hosseini & Chileshe, 2013; Lee & Yu, 2012). However, the industry's reliance on varied tools and processes that often do not integrate with one another presents a significant challenge. As noted by several scholars, the construction industry must strive to improve the interoperability of information systems to enhance the efficiency and effectiveness of collaboration (Park et al., 2011; Crotty, 2012).

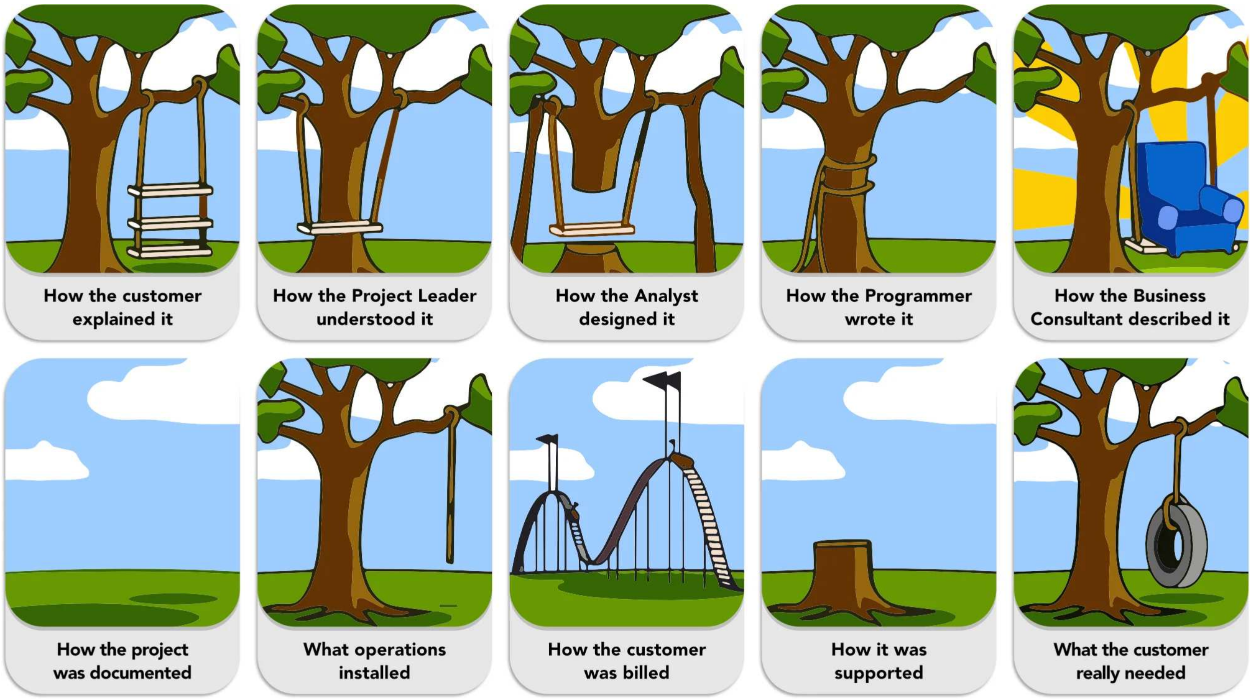


Figure 1.1: Poor information management, Kumar, 2015

Kumar B. (2015) believes that rather than project management simply being ‘the planning, organizing, monitoring and control of all aspects of a project and the motivation of all involved to achieve the project objectives safely and within agreed time, cost and performance criteria’, the industry should consider it fundamentally as an information processing enterprise with its ultimate goal being that:

“All stakeholders in any project share and exchange information in a pre-agreed standard format that is enabled by appropriate technologies, processes and standard protocols.”

According to Bryde D. (2013) and through its literature review, A document based way of working means that through the project life cycle there is an “unstructured stream of text or graphic entities” (BSI, 2010: 2). This unstructured stream poses a significant challenge to achieving better-integrated practices, as the information exchanged at the document level is often unclear, poorly formatted, or difficult to interpret. Then it indicates The rising interest in BIM that can be seen in conjunction with new PM frameworks, such as Integrated Project Delivery (IPD), and its framework which was developed as an answer to the complexity existing in AEC industry projects (The American Institute of Architects Official Guide 2007). This framework increases the need for closer collaboration and more effective communication (Eastman et al., 2011). When people collaborate on a project, effectively communicating specific characteristics of the project among the various parties involved requires proper documentation (Lee, 2008). Traditionally, this documentation was managed using paper-based or traditional document formats (BSI, 2010). BIM takes the traditional paper-based tools of construction projects, puts them in a virtual environment and allows a level of efficiency, communication and collaboration that exceeds those of traditional construction processes (Lee, 2008). Hence the coordination of complex project systems is perhaps the most popular application of BIM at this time.

1.3 Weaknesses and Obstacles to Collaboration

Another barrier is the lack of a unified approach to collaboration. The AEC industry is characterized by its diversity, with stakeholders often coming from different backgrounds, disciplines, and organizations. This diversity can lead to differences in expectations, communication styles, and work practices, which complicate the coordination of efforts (Dimitros, 2010). The challenge of aligning these different stakeholders can be particularly pronounced in international projects, where cultural, legal, and economic differences further complicate collaboration (Park et al., 2011).

Despite the clear benefits of collaboration, several weaknesses and obstacles impede its effectiveness in the AEC industry. One significant challenge is the lack of long-term engagement among stakeholders. Due to the temporary nature of project teams, collaboration often ends once the project is completed, and the relationships built during the project do not extend into future endeavors (Crotty, 2012). This lack of continuity prevents the development of standardized collaboration practices and knowledge sharing across projects.

Furthermore, the dynamic and project-specific nature of the AEC industry makes it difficult to establish standardized practices for information exchange and collaboration. The industry's tendency to prioritize short-term objectives and immediate project needs over long-term strategic goals results in a fragmented approach to collaboration. This fragmentation often leads to inefficiencies in communication, project management, and decision-making (Crotty, 2012).

As mentioned earlier, one key issue in the construction industry is the lack of a holistic approach among project teams, where the entire life cycle of the asset is not considered. Design teams often work in isolation, excluding key stakeholders like asset and facility managers, leading to overlooked issues that could be easily addressed if identified early. Similarly, constructability problems that contractors could resolve during the design phase become more complex and costly to fix later. This highlights the importance of early collaboration, as illustrated by the MacLeamy curve and BIM Task Group diagrams.

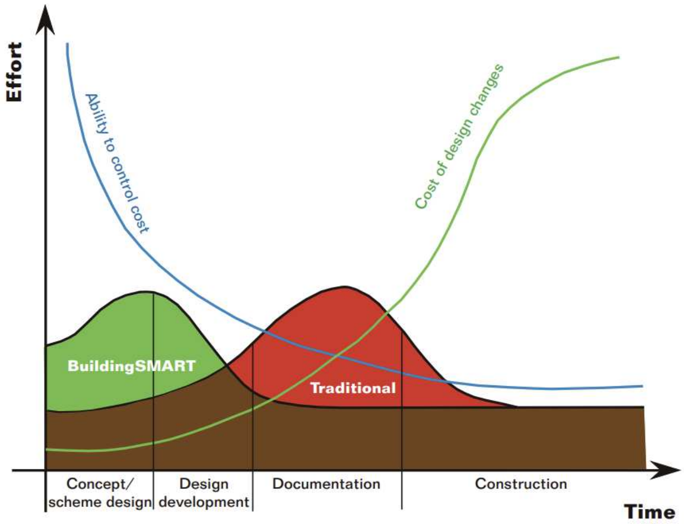


Figure 1.2: MacLeamy curve, Kumar, 2015

Bimal Kumar (2015) also refers to this fragmentation in the industry and he believes that this fragmentation generates so many issues that several other comparable industries just do not have to grapple with. He counts the following as some of the main issues regarding challenges of information flow and exchange in the construction industry:

- The vast majority of the industry comprises micro firms, who cannot afford the infrastructure or expertise for seamless information exchange with other stakeholders in a project.
- No single organization has the financial muscle power and influence to enforce industry-wide standards for information exchange. In most markets, no single organization in this industry has more than a low single-digit market share, unlike several other industries such as high-technology industries (for example) where Intel had an 80%+ share of the microprocessor market (Digikey, 2011) in 2010.
- Linked with the point above, there is a lack of agreed standards for information exchange that cover all aspects of the architecture, engineering, and construction industry.
- The discrete nature of project delivery processes with disjointed stakeholders gives rise to a lack of seamless coordination and collaboration.
- The constantly dynamic relationships between stakeholders due to the project- rather than product-based nature of the industry create complexities.

Later on he uses Figure 2 which is an attempt to capture the track record of the construction industry on megaprojects to clarify more the reasons of program failures and obstacles in mega projects. Figure 3, the pie chart on the right gives a breakdown of the possible causes of failures on large construction projects. It is clear from the pie chart on the left that the vast majority of large projects tend to underperform, whereas the chart on the right suggests that only a small proportion of the failures are due to technical difficulties and that the vast majority of failures are due to non-technical issues. The three largest categories in this chart are Poor Organisation and Project Management Practices, Poorly Defined or Missing Project Objectives and Ineffective Project Planning. Between them, they constitute some 71% of the causes of project failures.

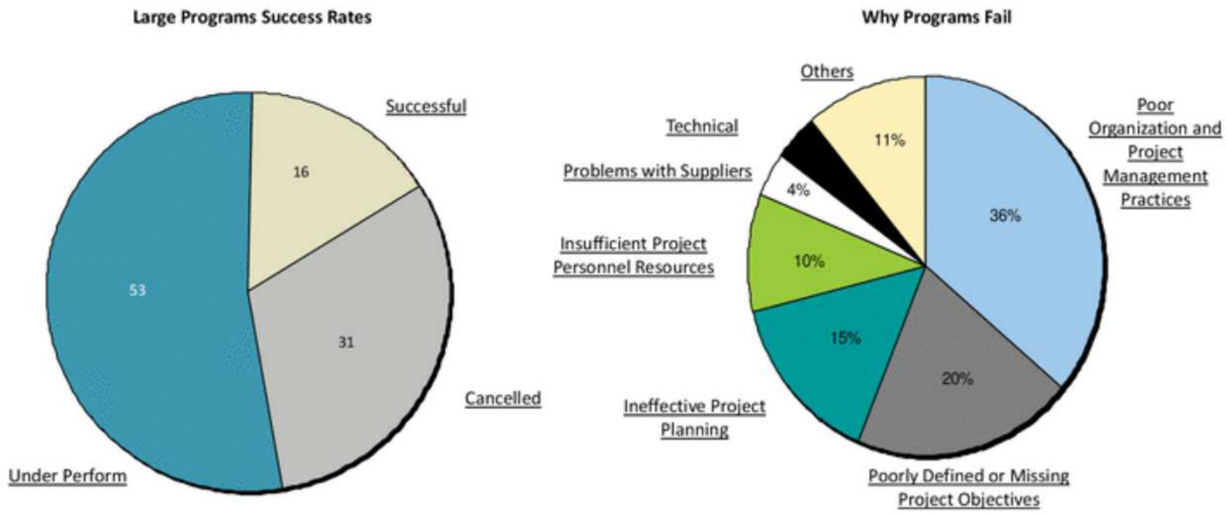


Figure 1.3: Failure on mega projects, Kennerson, 2013

Interestingly, one can easily attribute all these three categories to lack of high-quality information management in one way or another.

In summary, collaboration plays a fundamental role in the success of AEC projects, but the industry's inherent complexities and fragmented workflows present significant challenges. Effective information management and the adoption of integrative tools like BIM can address many of these obstacles, fostering better communication, coordination, and efficiency. This chapter establishes the foundation for exploring how BIM-based methodologies can serve as transformative solutions to collaboration challenges in the AEC industry.

Chapter 2

2. Internships Experiences and Their Role in Shaping the Thesis Subject

2.1 Introduction

This chapter explores the internship experiences of both authors, Behrad Zolfagharzadeh and Sahar Tajzadeh, which played a crucial role in shaping the focus of this thesis. These internships provided first-hand exposure to the challenges of collaboration, project management, and workflow dynamics within the architectural field, particularly in the context of international and multidisciplinary collaborations. By examining these experiences, the chapter highlights the practical difficulties faced during project execution in traditional, non-BIM workflows. These observations informed the thesis’s emphasis on general collaboration challenges within the Architecture, Engineering, and Construction (AEC) industry.

The case study of this thesis is the extension of Yuan Ding Middle School, a project conceptualized and developed as part of this research. This work draws inspiration from insights gained through Turin Design Hub's (TDH) renovation of the existing school, which, as further detailed in subsequent paragraphs, is a group of twelve Turinese firms collaborating with Chinese partners and a research group from the Politecnico di Torino. TDH serves as an example of how traditional CAD workflows operate without the integration of Building Information Modeling (BIM). This understanding provided a foundation for investigating how BIM-based methodologies could address these challenges and enhance collaborative practices across the AEC industry.

2.2 Context of the Internship (Behrad Zolfagharzade)

2.2.1 China Room

My internship was conducted at the China Room of Politecnico di Torino, an interdisciplinary research team consisting of scholars in the fields of architecture, urbanism, and geography, who study the influence of Global China and Chinese urbanization processes. Additionally, the China Room promotes collaboration with institutions and universities to facilitate knowledge exchange and enhance mutual understanding of urban and architectural practices (Chinaroom Website).

2.2.2 Polito Studio

Within my experience in China Room, another key initiative relevant to this context is Polito Studio. Polito Studio represents a collaborative experiment that bridges academia and professional practice. Based at the Politecnico di Torino, this initiative brings together diverse disciplines to tackle complex challenges in urban and architectural design. It has positioned itself as a hub of expertise, fostering connections between Italy and China in the field of architecture advancing innovative projects in diverse urban contexts. As highlighted by Forina (2024), the studio's achievements stem from its ability to integrate theoretical insights with practical execution, thereby facilitating impactful contributions to both the academic and professional domains.

Polito Studio operates on several foundational principles that reinforce its commitment to bridging research and practice. At its core, this initiative fosters **collaboration and knowledge sharing**, creating a flexible framework for mutual learning that enhances professional skills and facilitates access to international markets for local firms. By promoting **inclusive networking**, it connects firms of varying sizes, establishing an environment where knowledge transfer and collaborative innovation thrive. A key aspect of its approach is **empowering local practitioners** through workshops and collaborative practices, equipping them with the tools to navigate international markets independently and contribute to a growing knowledge ecosystem. The studio is also rooted in **transdisciplinarity**, emphasizing practical solutions to real-world challenges by integrating diverse disciplines such as architecture, urban planning, and engineering. This commitment to **innovation** ensures that projects are driven by research, digital tools, and advanced methodologies, enabling seamless cooperation between academia and practice while addressing contemporary urban and architectural challenges.

These principles enable Polito Studio to address multifaceted challenges with a holistic perspective, ensuring its projects not only meet immediate needs but also contribute to broader societal goals.

2.2.3 TDH (Turin Design Hub): A Key Outcome of Polito Studio's Efforts

One of the most significant achievements of Polito Studio is the establishment of the Turin Design Hub (TDH), which serves as a cornerstone for integrating academic insights with professional architectural practices. TDH exemplifies Polito Studio's vision by creating a collaborative platform where academia and practice intersect, fostering an environment conducive to innovation, experimentation, and knowledge transfer. The hub has been instrumental in enabling the seamless flow of ideas between researchers, practitioners, and students (Forina, 2024), as seen in its projects like the Nanshan 100 Campus Renewal Plan.

The development of TDH reflects Polito Studio's commitment to fostering collaboration and mobilizing resources effectively. As a network of firms, TDH brings together local Italian companies and Chinese institutions, creating a platform for interdisciplinary teamwork and knowledge exchange. By leveraging this structure, TDH has facilitated the development of design solutions that address complex architectural and urban challenges, including the integration of sustainable building practices and responsiveness to local socio-cultural contexts. Through its collaborative framework, TDH encourages innovation by bridging diverse expertise, fostering a dynamic environment where firms can collectively navigate international projects and explore new methodologies in architectural and urban design.

2.2.4 The Role of Collaboration in Polito Studio and TDH

Central to the missions of Polito Studio and TDH is the emphasis on fostering collaboration among firms and academic institutions. By promoting partnerships between firms of varying sizes and expertise, these initiatives create an inclusive and dynamic environment for knowledge sharing and collective problem-solving. This approach not only broadens the reach of local firms but also enhances their ability to tackle complex challenges in international markets.

The importance of managing information effectively in such collaborative frameworks is paramount. As emphasized in Chapter One of this thesis, inter-firm collaborations require robust systems for data organization, communication, and iteration. Polito Studio and TDH exemplify this need by integrating diverse stakeholders and fostering an environment where mutual learning and coordinated workflows are essential for success.

2.2.5 Responsibilities and Observations During the Internship

During my internship, I contributed to two significant projects under the Nanshan 100 Campus Renewal Program in Shenzhen, China. This initiative aimed to renovate and enhance educational facilities across Shenzhen, focusing specifically on the renewal of one kindergarten and one middle school. As an intern in the China Room team, my responsibilities included:

Behrad’s Responsibilities in China Room	
Responsibilities	**Description**
Organizing 3D and 2D Files	Streamlining and managing design documentation to ensure consistency and accessibility.
Redrawing 2D Files	Updating and refining technical drawings to meet project requirements.
Merging 3D Files	Consolidating models from different architectural firms to create cohesive representations.
Creating Cost Estimation Tables and Editing Them	Preparing detailed financial analyses for interior design components.

Table 2.1: Behrad’s Responsibilities in China Room

These tasks required a high level of precision and coordination, reflecting the complexity of managing information and collaboration across multiple firms.

While performing these tasks, I gained valuable insights into the workflow and identified certain areas where improvements could potentially enhance efficiency and coordination. For example, regarding general workflow observations:

Managing information and communication across international teams emerged as a significant challenge during my internship. The coordination primarily relied on platforms like chat and video calls, which were effective but challenged by the considerable time zone differences between Italy and China. This often delayed iterative feedback and slowed down the overall design process. Moreover, the cyclical nature of reworking designs, receiving feedback, and making adjustments highlighted inefficiencies often found in traditional non BIM workflows. These experiences highlighted the importance of adopting more streamlined processes and effective tools to improve collaboration and efficiency.

During this time, I had two particularly significant experiences that provided valuable learning opportunities. These experiences centered on **Quantity and Cost Estimation** during the Yuan Ding School renovation project and **Conceptual Modeling Challenges** encountered while participating in a competition project.

One specific area where these workflow challenges became apparent was in the renovation of Yuan Ding Middle School, specifically when I focused on the interior design of a classroom. A key task involved preparing a detailed table of quantities and costs for materials, such as paint, flooring, lighting fixtures, and furniture. Using Microsoft Excel, I calculated quantities based on dimensions extracted from AutoCAD and SketchUp files, leveraging square meter measurements to estimate material needs accurately.

However, as the design evolved, significant changes necessitated a complete recalibration of these estimates. This process of starting over each time highlighted the limitations of a CAD-based workflow, where disconnected tools like AutoCAD and Excel required manual recalculations, leading to inefficiencies and potential errors. In contrast, a Building Information Modeling (BIM) workflow could have integrated material data with 3D models, allowing real-time updates to quantities and costs as designs changed. Such an interconnected system would not only save time but also ensure accuracy and consistency across project documentation. This experience emphasized the transformative potential of BIM for tasks requiring frequent updates and coordination.

Another critical learning opportunity arose during my involvement in a competition project, where the team initially decided to use Revit for the conceptual design phase. Revit's integration of conceptual and detailed design within a single platform was appealing; however, its limitations became apparent as the project progressed. Conceptual design inherently requires frequent iterations and flexibility to explore ideas such as altering building heights, adjusting masses, or experimenting with spatial arrangements. Revit's parametric structure and detailed modeling capabilities, more suited for later stages of design, made these iterative changes slow and restrictive. Simple adjustments, such as modifying the height of a mass, became time-consuming and slowed down the creative flow.

Reflecting on this experience, it became clear that alternative tools like Rhino could better support the iterative nature of conceptual modeling. Rhino's flexibility, intuitive interface, and compatibility with other design software make it particularly effective for rapid modifications and experimentation. Adopting such a tool would not only streamline early-stage workflows but also foster creativity and ensure smoother transitions from concept to detailed design. This observation underscores the importance of selecting tools that align with the specific demands of each design phase to enhance efficiency and innovation.

2.3 Context of the Internship (Sahar Tajzadeh)

My internship took place at the **Drawing TO the Future**, a research and teaching laboratory at the Politecnico di Torino, coordinated by Professor Anna Osello. The lab focuses on finding innovative ways to manage and represent information in the built environment. It adopts a multidisciplinary approach, combining tools and methods like **Building Information Modeling (BIM)**, which supports collaboration through ideal data sharing; **Geographic Information Systems (GIS)** for analyzing and managing geographic data; and **Interoperability**, which ensures smooth integration of data from different sources. The lab also explores technologies such as **3D Printing**, **Virtual and Augmented Reality**, and **Video Editing** to improve communication, visualization, and prototyping. These methods are applied to create solutions that address current challenges while anticipating future needs (Drawing To the Future Website).

During my internship at the lab, I focused on researching BIM (Building Information Modeling) and HBIM (Heritage Building Information Modeling), particularly their role in addressing interoperability among software, communication challenges, and data management issues. I also studied how BIM enhances collaboration by enabling better file organization, real-time teamwork, and efficient data sharing among stakeholders.

In addition to research, I gained practical experience in how projects are managed in a BIM-driven environment. I observed how tools like **Revit**, **Navisworks**, and **BIM Collaboration Format (BCF)** simplify the design process and promote collaboration across teams. These tools not only improved data organization and reduced errors but also made workflows more efficient overall. Seeing these tools in action helped me appreciate the practical benefits of BIM for project management and coordination.

This experience gave me a clearer understanding of how BIM can address common challenges in architectural workflows, such as communication breakdowns, inefficient data management, and model integration issues, by enabling real-time collaboration, automating clash detection, and providing a centralized platform for better organization and coordination among team members. These challenges closely mirror the problems explored in this thesis related to traditional 2D CAD workflow. My internship provided a strong foundation for understanding how BIM can improve data management and project outcomes—an approach that shapes the solutions proposed for the Yuan Ding School Extension Project.

2.4 Conclusion

The internship experiences of both authors significantly shaped the direction and scope of this thesis. Behrad's involvement in the Politecnico di Torino's China Room and TDH provided first-hand exposure to the complexities of international collaboration and traditional workflows, revealing challenges in information management, communication, and iterative processes. Sahar's internship at Drawing TO the Future Lab complemented this perspective by showcasing the potential of Building Information Modeling (BIM) to enhance data sharing, collaboration, and workflow efficiency.

In collaboration with the China Room and TDH, a questionnaire was developed to gain a deeper understanding of the traditional, non-BIM-based workflow employed within TDH. This survey provided perspectives from team members and partners, revealing the limitations and challenges inherent in conventional collaboration practices. These findings offered a basis for analyzing the broader challenges of traditional workflows and exploring how BIM-based methodologies could address these issues within the AEC industry. The findings help us to understand how traditional workflows operate and how BIM-based methodologies can offer solutions to enhance collaboration and efficiency across the AEC industry.

2.5 Conducting the Questionnaire

To better understand TDH's existing workflow, collaboration challenges, and the potential for BIM-based solutions, a questionnaire was conducted and distributed among TDH employees. The survey focused on key aspects such as current tools and software usage, cross-team collaboration, data management, and familiarity with BIM.

The analysis of the responses provided insights into the challenges and priorities within TDH's workflow and collaboration practices, offering a deeper understanding of traditional, non-BIM workflows. This section reviews the findings question by question, highlighting trends, challenges, and opportunities. The insights gained provide a foundation for understanding traditional practices and exploring how BIM-based methodologies could address these challenges and improve collaboration within the AEC industry.

The questionnaire was structured into four main sections, each targeting a key aspect of the workflow and collaboration processes. The purpose of these sections was to uncover challenges, identify opportunities, and gather insights to better understand traditional, non-BIM workflows and their inherent limitations.

2.5.1 Questionnaire Sections

Below is a breakdown of each section:

Section 1: Current Workflow and Collaboration

This section explored the tools and software currently used by TDH, how well they integrate across teams, and the challenges experienced in cross-team collaboration. It focused on:

- The tools and software used by team members and their integration with others.
- Handovers between teams or project stages, and their effectiveness.
- The main challenges in collaboration.

Section 2: Data Management and Project Coordination

This section examined the management and coordination of project data, focusing on file storage, access issues, and version control. It aimed to:

- Identify how project files are managed and shared across teams.
- Explore the adequacy of the current data management system.
- Address challenges with data loss, file corruption, and outdated files.

Section 3: Familiarity with BIM and Potential Improvements

This section gathered feedback on the team's familiarity with BIM tools and their perception of BIM's potential impact on workflow improvements. It focused on:

- The level of familiarity with BIM tools like Revit.
- The possible benefits of BIM.
- Potential obstacles to adopting BIM.

Section 4: Additional Input

The final section gathered additional feedback on the support needed for adopting a new BIM workflow. It focused on:

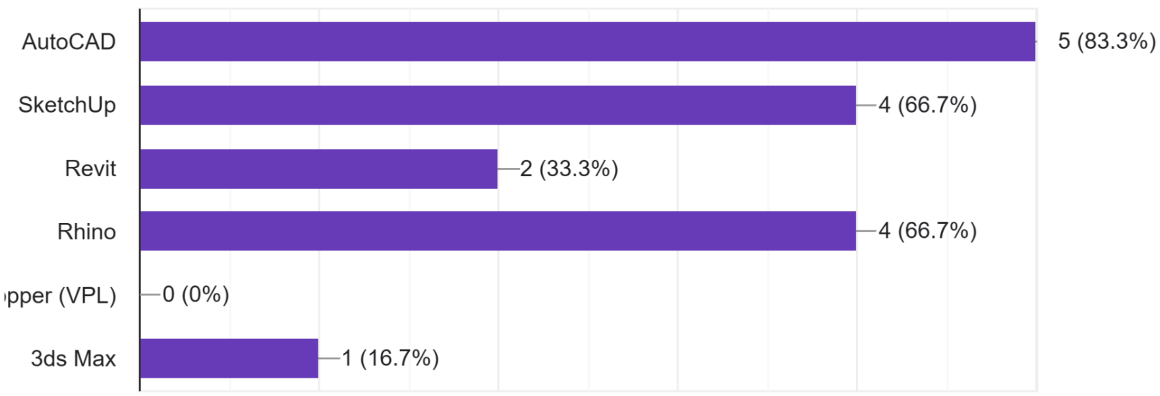
- The types of support required, such as clear workflow guidelines, training, and mentorship.
- The preferred approach for integrating BIM into TDH’s workflow.

2.5.2 Results and Analysis of the Questionnaire

Number of participants: 6

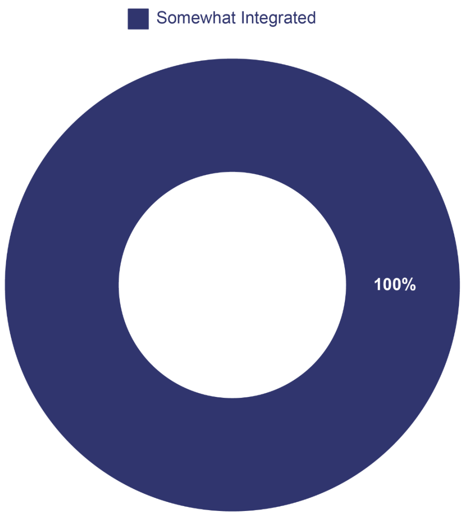
Section 1: Current Workflow and Collaboration

1. What tools or software do you primarily use in your work as a TDH member?



The dominance of AutoCAD and SketchUp indicates reliance on traditional 2D and basic 3D tools, with limited use of BIM tools like Revit. Dynamo/Grasshopper's absence suggests that parametric and algorithmic design approaches are not part of TDH's workflow.

2. How well do the tools or software you use integrate with those used by other teams in TDH?



a) Very well integrated

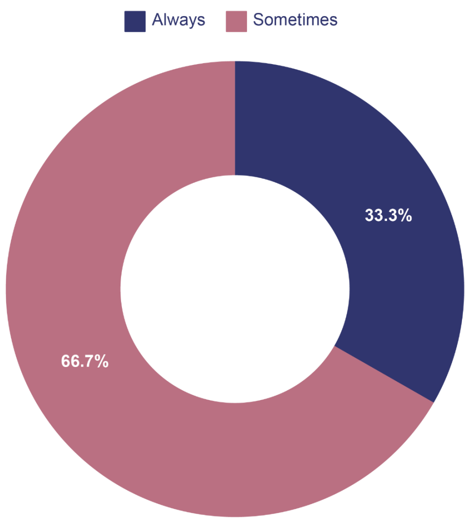
b) Somewhat integrated

c) Not integrated at all

d) I don't know

While the tools allow partial collaboration, there is no seamless integration. This suggests Problems when exchanging data between teams or stages of the project.

3. How often do you experience issues with handovers between different teams or stages of a project?



a) Always

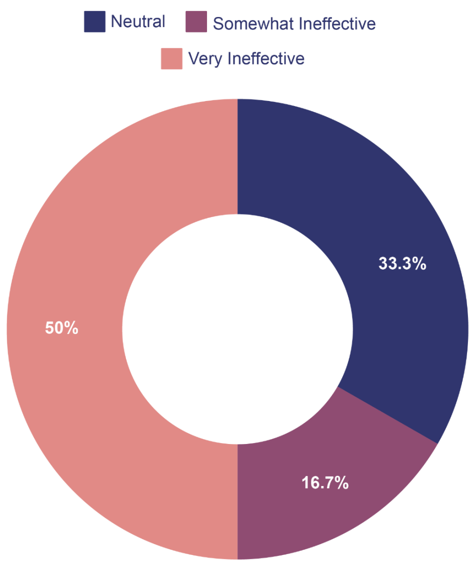
b) Sometimes

c) Never

Handovers are consistently problematic, with no participants reporting smooth transitions. This highlights coordination and workflow problems among teams.

BIM's potential for centralized file sharing and real-time updates directly addresses these handover issues, ensuring smoother transitions across project stages.

4. How would you rate the effectiveness of the current design workflow at TDH?



a) Very effective

b) Somewhat effective

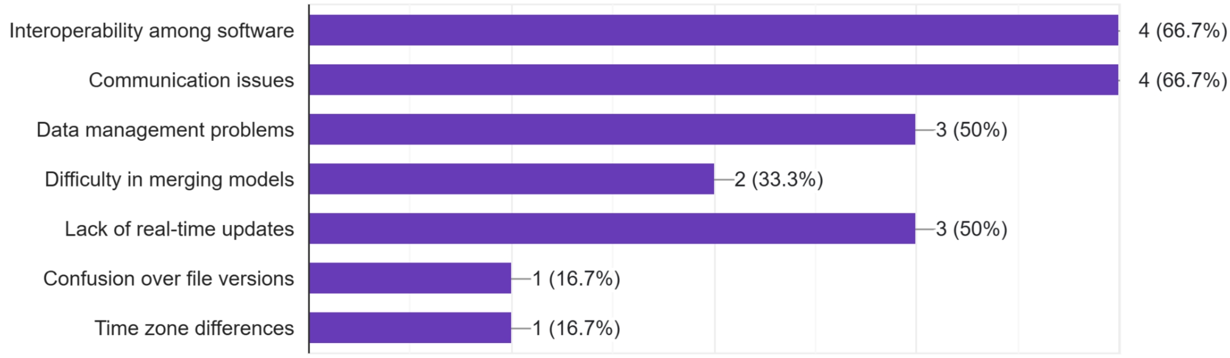
c) Neutral

d) Somewhat ineffective

e) Very ineffective

The workflow is widely perceived as ineffective, lacking the ability to meet deadlines, reduce errors, or enable clear communication.

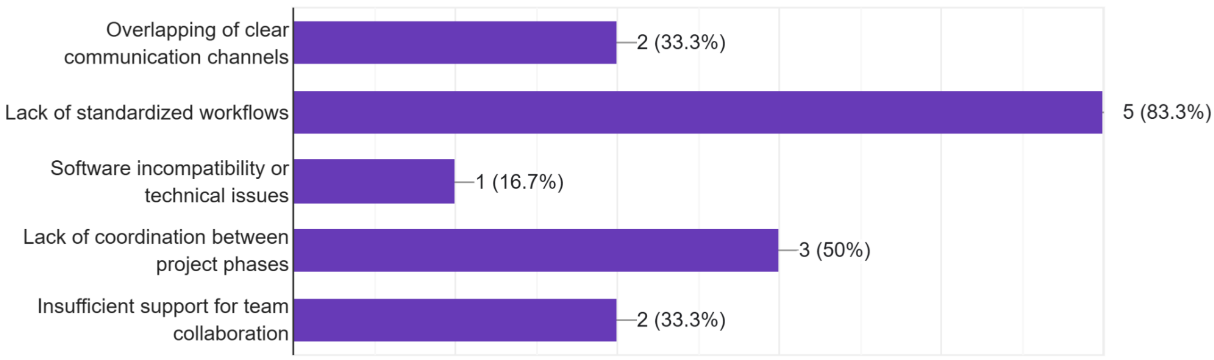
5. What are the biggest challenges you face in cross-team collaboration?



The most significant challenges revolve around Software compatibility and communication. Data management and real-time collaboration also have problems, while file version confusion and time zones are less problematic.

The BIM workflow could tackle these challenges through standardized file formats, centralized data environments, and real-time collaboration tools.

6. What are the primary causes of the challenges you face in cross-team collaboration?

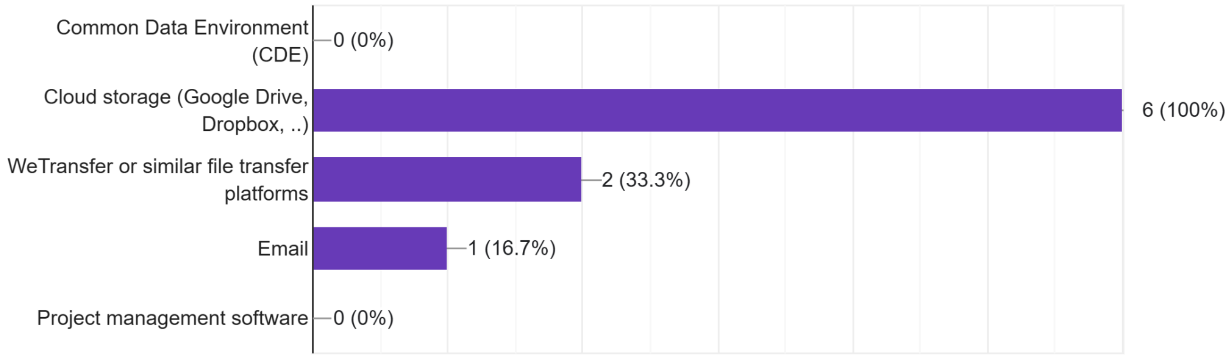


The lack of standardization is the leading issue, followed by poor phase coordination.

Standardized BIM workflows directly address the lack of consistency, while phase coordination could be improved with BIM-supported project tracking tools.

Section 2: Data Management and Project Coordination

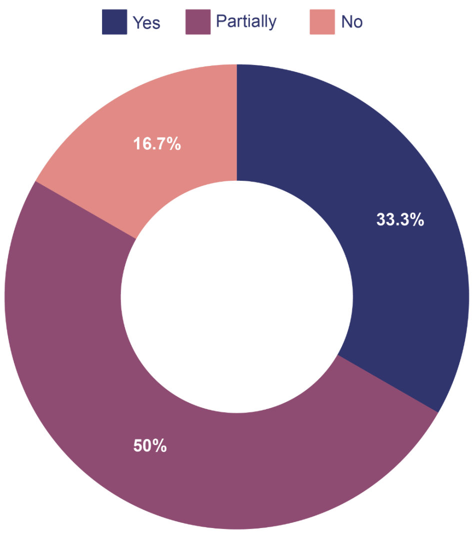
7. How do you primarily manage project files and data?



While cloud storage is the primary method, reliance on tools like email and WeTransfer suggests fragmented data management and a lack of secure, centralized systems.

Implementing a common data environment (CDE) could centralize file storage and enhance collaboration efficiency.

8. Do you think the current data management system adequately supports cross-team collaboration?



a) Yes

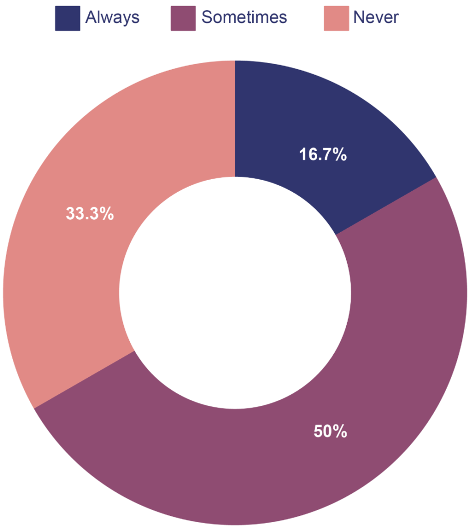
b) Partially

c) No

d) Not sure

The current system is functional but not fully effective.

9. How often do you experience issues with data loss, corruption, or access problems in project files?



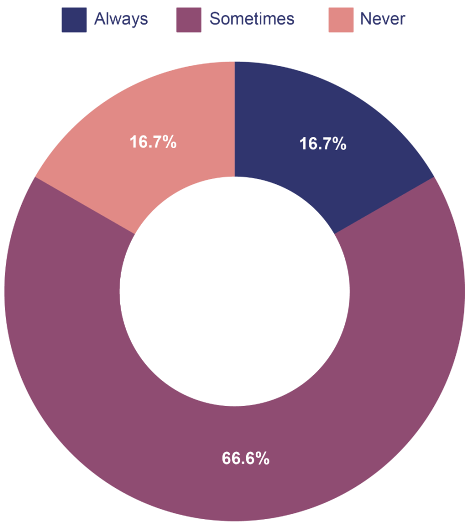
a) Always

b) Sometimes

c) Never

Data issues occur frequently enough to disrupt workflows, though not universally. BIM systems with version control and secure storage could mitigate these problems by reducing risks of data corruption or loss.

10. How often do you face problems with project files being outdated, having conflicting versions, or difficulties with file sharing?



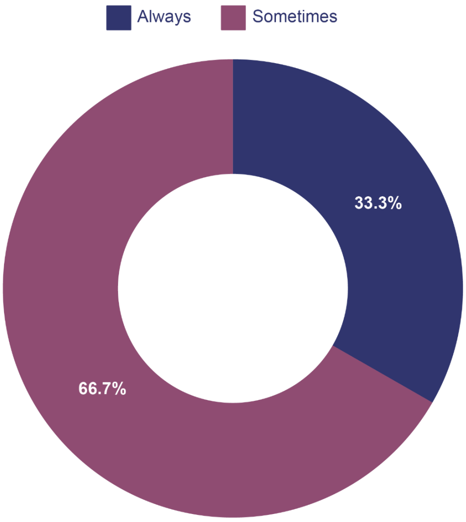
a) Always

b) Sometimes

c) Never

Versioning and sharing issues are a consistent problem for most respondents, with only a minority avoiding them. A CDE and real-time updates could reduce outdated and conflicting file issues.

11. How often do you encounter problems when integrating 3D models from different collaborating firms within TDH?



a) Always

b) Sometimes

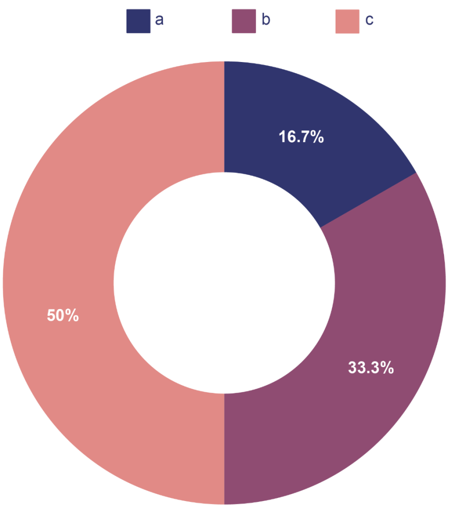
c) Never

Model integration issues are common, reflecting a lack of interoperability or standardized modeling practices.

BIM's interoperability features and clash detection tools directly address these integration issues.

Section 3: Familiarity with BIM and Potential Improvements

12. How familiar Are you with BIM tools like Revit?



a) Very familiar, I use them regularly

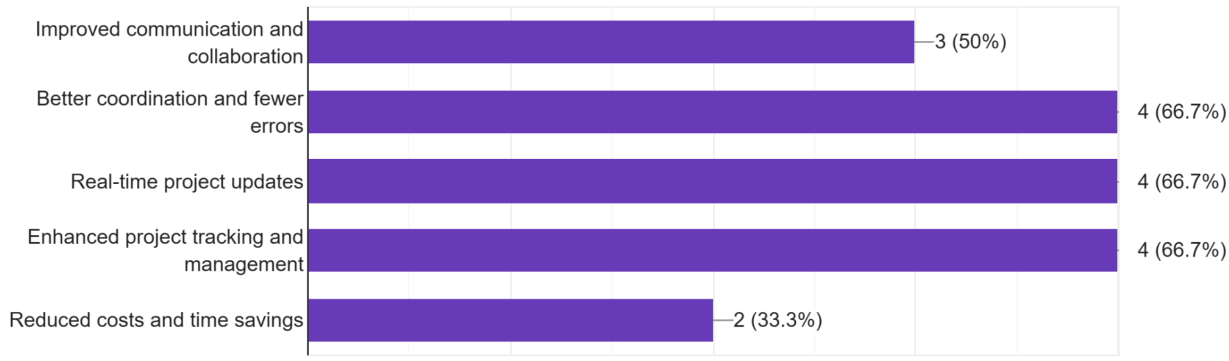
b) Somewhat familiar, I have used them occasionally

c) I've heard of them but never used them 50

d) Not familiar at all

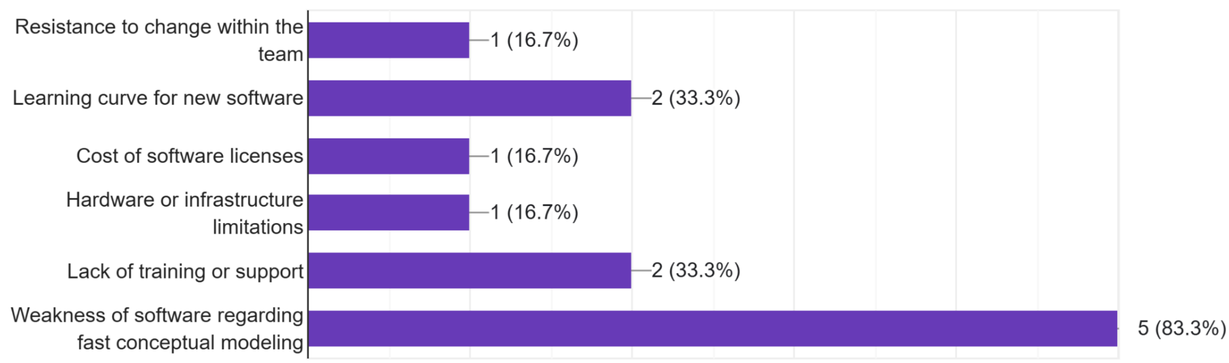
Most employees have limited or no experience with BIM tools.

13. What benefits would you like BIM to bring to TDH’s workflow?



Coordination, tracking, and real-time updates are highly prioritized, while cost/time savings are less critical.

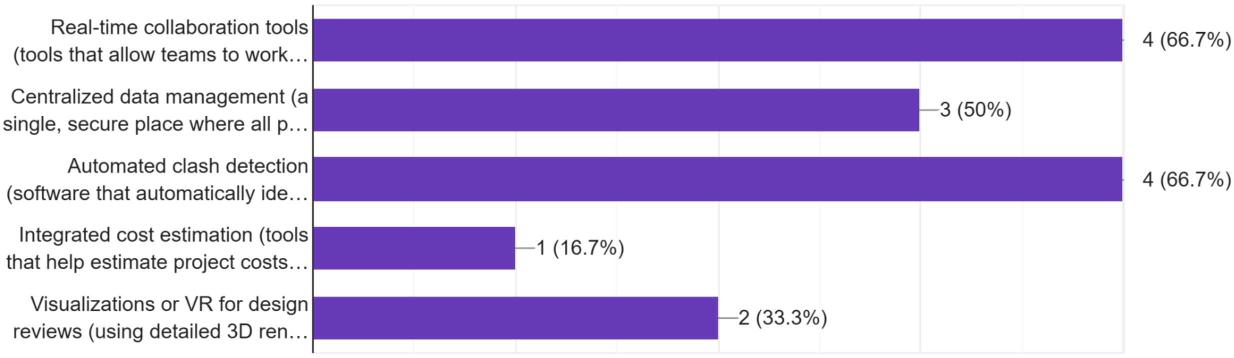
14. What do you see as potential obstacles to adopting a BIM-based workflow at TDH?



The primary concern is that BIM tools are perceived as unsuitable for quick conceptual design, which is likely an essential part of TDH’s workflow. Secondary obstacles like training gaps and steep learning curves highlight the need for a smooth onboarding process.

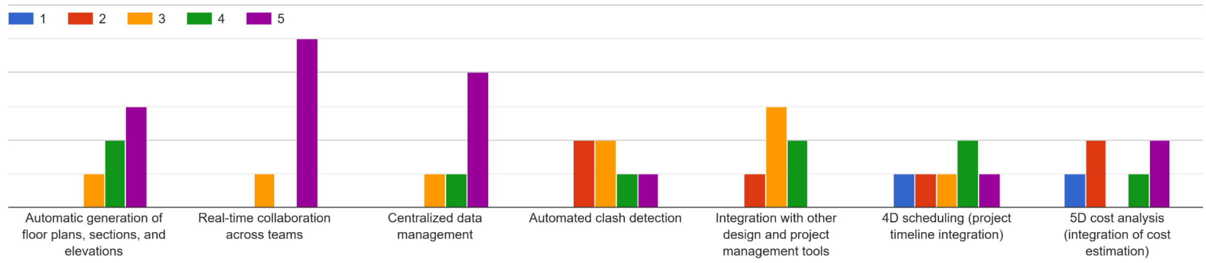
A hybrid workflow could be proposed where fast conceptual modeling tools, such as Rhino, coexist alongside BIM software like Revit for detailed design and documentation.

15. What features or tools would be most useful in a new workflow to improve your work efficiency?



The team places high value on real-time collaboration and automated error detection, highlighting their need for tools that directly address coordination and accuracy challenges. Cost estimation is less of a priority, reflecting a focus on design over budgetary concerns.

16. Please rate the importance of the following BIM features in improving design workflow and collaboration at TDH (1 = Least important, 5 = Most important).



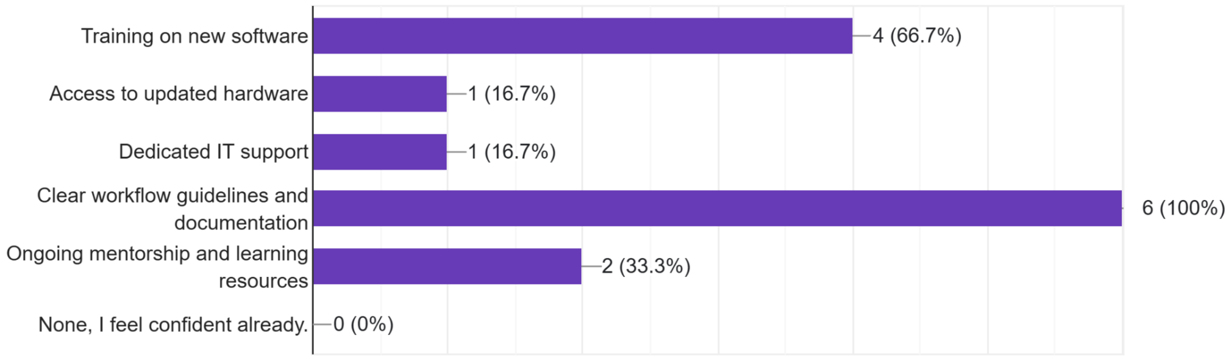
Priorities: Real-time collaboration and centralized data management are the most critical BIM features for the team, signaling a demand for enhanced communication and a cohesive data environment.

Secondary Needs: Features like automated clash detection, integration with other tools, and automatic generation of documentation are still significant but not as urgent.

Lower Emphasis: 4D scheduling and 5D cost analysis, though valued, may be less immediate concerns compared to collaboration and data management.

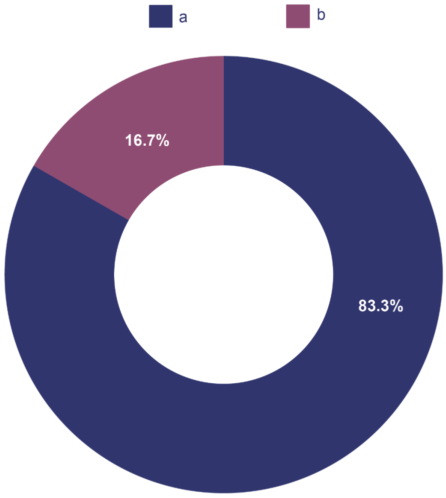
Section 4: Additional Input

17. If TDH were to adopt a new BIM workflow, what support would you need?



The team's top priority is clarity and structure in the form of guidelines.

18. If TDH were to integrate BIM into its workflow, which approach do you believe would be most effective?



a) Appointing a dedicated BIM specialist for each office to provide tailored support and expertise.

b) Partnering with an external BIM consultancy or company to implement and manage the workflow.

c) Providing relevant courses for employees to learn BIM Workflow 0

d) Other (please specify): _____________

The team strongly prefers an in-house BIM expert over external consultants or generalized training courses.

2.5.3 Key Insights and Challenges Identified

The questionnaire analysis provided valuable insights into the challenges and characteristics of traditional, non-BIM workflows. Respondents highlighted issues such as difficulty in merging models, handling outdated project files, and managing software integration and interoperability among tools. Additional challenges included version control, lack of real-time updates, and the complexities introduced by time zone differences in international collaborations. These observations underscore the limitations of traditional workflows in managing project data and facilitating seamless collaboration.

The findings from the questionnaire analysis shed light on how traditional workflows operate within TDH, particularly the difficulties associated with file sharing, outdated models, and tool integration. These insights are not intended as critiques but rather as reflections on the challenges inherent in conventional practices. Understanding these dynamics is essential for identifying areas where collaborative strategies and innovative approaches, like BIM, have the potential to address these challenges more broadly within the AEC industry.

By examining these challenges, this thesis aims to explore how BIM-based methodologies can provide solutions to improve data management, facilitate real-time collaboration, and enhance interoperability. The findings from the questionnaire serve as a foundation for analyzing the broader opportunities BIM offers in addressing inefficiencies and fostering effective collaboration across project teams.

Chapter 3

3. Objectives of the Thesis

3.1 Research Goals

This thesis focuses on understanding how collaboration challenges in the Architecture, Engineering, and Construction (AEC) industry can be addressed, with particular attention to the limitations of traditional workflows and the potential offered by Building Information Modeling (BIM).

The study aims to:

1. Investigate the challenges and inefficiencies in traditional 2D CAD workflows, particularly their impact on communication, data management, and project efficiency in multidisciplinary and international contexts.

2. Examine how BIM-based methodologies can enhance collaboration, streamline project workflows, and optimize outcomes through features like real-time data sharing, interoperability, and advanced analysis tools.

3. Analyze the practical applications of BIM in addressing key collaboration challenges, using **the Yuan Ding Middle School extension project and a controlled workflow simulation** as case studies.

4. Explore the potential of BIM to address general inefficiencies in the AEC industry, offering broader insights into collaborative practices and project execution.

5. Compare **BIM-based workflows with traditional CAD-based workflows through a structured simulation**, evaluating how each method affects coordination, change management, accuracy, and efficiency.

6. Provide a framework for understanding how BIM can support more effective collaboration across diverse AEC projects, highlighting its strengths and limitations.

3.2 Proposed Scope of Work

To achieve these goals, this thesis explores the following areas:

1. Analysis of Traditional Workflows

- Examine the limitations of 2D CAD-based workflows, including inefficiencies in communication, iterative rework, and data fragmentation.
- Highlight the challenges of integrating diverse disciplines and stakeholders in traditional AEC projects.

2. Introduction and Exploration of BIM

- Provide an in-depth overview of BIM tools, methodologies, and standards, including ISO 19650, Autodesk Construction Cloud, and Revit.
- Analyze BIM's advanced dimensions, such as 4D scheduling and 5D cost estimation, and their practical applications in improving project management and collaboration.

3. BIM vs. CAD Workflow Simulation

- Conduct a **workflow simulation** comparing **BIM-based collaboration (Revit) and CAD-based collaboration (AutoCAD & SketchUp)**.
- Assess **collaboration efficiency**, **change management**, **accuracy**, and **time investment** across both workflows.
- Demonstrate **real-time synchronization in BIM (Revit's Collaborate tab)** versus **manual data transfer in CAD**.

4. Development of a BIM-Based Workflow

- Propose a workflow designed to address the challenges identified in traditional systems, emphasizing real-time collaboration, centralized data management, and interoperability.
- Integrate the workflow with specific tools and processes, including shared coordinates, Revit phases, Employer Information Requirements (EIR), and BIM execution plans (BEP).

5. Case Study Application

- Apply the proposed BIM workflow partially to the extension of Yuan Ding Middle School, showcasing its capacity to optimize project outcomes through advanced analysis tools and collaborative methods.
- Demonstrate specific applications like 4D time simulation.

6. Recommendations and Future Directions

- Offer insights for improving BIM adoption across AEC projects, focusing on training, standardization, and organizational readiness.
- Provide a roadmap for implementing BIM workflows in diverse project settings.

3.3 Limitations

While this thesis explores the transformative potential of BIM workflows, several limitations are acknowledged:

1. **Scope of the Case Study:**
   The proposed workflow is primarily demonstrated through its application to the Yuan Ding Middle School extension project. While this provides valuable insights into the potential benefits and challenges of the workflow, it does not completely apply to all aspects of the project due to certain constraints. For example, as students, we faced software license limitations, such as restricted access to Autodesk Construction Cloud (ACC). In these situations, we relied on references and literature to explain the processes theoretically, rather than implementing them directly. This limitation highlights the need for further exploration and validation in real-world scenarios with full access to the required tools and software.

2. **Focus on Specific Tools:**
   The research focuses on tools like Revit and Navisworks while other BIM platforms and software solutions (ex. ArchiCAD) are not explored at all.

3. **Geographical and Cultural Contexts:**
   The case study involves international collaboration, particularly in the design and construction processes. However, it is important to note that every country has its own unique cultural, regulatory, and organizational frameworks that influence project execution. Factors such as building codes, legal requirements, communication norms, and organizational hierarchies can vary significantly across regions. While the findings provide valuable insights into collaborative workflows, they may not fully

address these differences or offer solutions adapted to the specific complexities of every geographical or cultural context.

4. **Technological Adaptation Challenges:**
   The thesis proposes advanced BIM methodologies, such as real-time collaboration, centralized data environments, and the use of tools like Revit, Navisworks, and Autodesk Construction Cloud. However, implementing these methodologies requires significant technological adaptation, which may include upgrading existing software, acquiring new tools, and ensuring compatibility across platforms. Additionally, team members need extensive training to effectively use these technologies, and organizations may face high upfront costs for software licenses, hardware upgrades, and cloud-based storage solutions. For example, adopting Autodesk Construction Cloud (ACC) requires both technical and organizational readiness. Teams must transition from traditional, file-based workflows to cloud-based collaboration, which may demand reliable internet infrastructure and a commitment to ongoing training. In some cases, smaller firms or teams with limited budgets may find it challenging to justify the initial investment. Furthermore, individuals who are unfamiliar with cloud-based workflows may face a steep learning curve, potentially leading to inefficiencies during the transition phase. These challenges highlight that while the proposed BIM workflow offers substantial long-term benefits, its immediate adoption could be constrained by the resources, training, and technological infrastructure available to the implementing organization.

Chapter 4

4. BIM based workflow

4.1 Introduction

As mentioned in the first chapter, the complexity and challenges existing in the AEC industry nowadays, stem from inefficient data management (Latham, 1994; Egan, 1998). In this thesis we chose the BIM based workflow as an answer to this inefficiency and with the help of the literature review, a simulation, and a case study done by us at the end of the thesis, we will indicate the ways that this approach can help architects and design firms to optimize their workflow.

4.2 2D CAD Traditional Workflow Analysis

4.2.1 Overview of Traditional 2D CAD Workflows

,Challenges and Limitations of 2D CAD in Modern AEC Projects

Firstly, let's ask this question: why the traditional 2D CAD workflow can be inefficient and problematic?

Despite the clear global push towards implementing BIM in construction projects, its adoption has been somewhat sluggish compared to other industries (Farea, 2024). This indicates that many firms still use the traditional 2D CAD Workflow and as a consequence they are also obliged to utilize a regular 3D model Program which is just a 3D representation tool and does not contain any smart information (Eastman, 2011), which its importance is quite clear in project management.

Al Hattab M. (2013) indicates that the flow of information among players and project stages in traditional 2D CAD projects is jumbled. Then a cross functional (swim-lane) diagram was used in the same research to model the traditional 2D CAD design phase information flow. It is mentioned that this diagram was used to represent three things simultaneously:

- Information Flow
- Clear Information Exchange among different participants
- Data Deliverables resulting from each design process

The Diagram is divided horizontally into three lanes (Architect/Designer, Structural/Civil Engineer, and MEP Engineer). The diagram is divided vertically into four phases. The first phase is the conceptual design phase, followed by review and iterations (rework) period when the conceptual design phase tentatively ends, and once the review period and any rework has been performed and accepted by the owner, the schematic design phase is triggered. In a similar fashion, it is followed by a review and iterations period once the schematic design phase tentatively ends. Once the owner grants approval, the design teams move forward to the detailed design phase, which is typically more streamlined and less complex. Architects initiate this process by creating the design concept and producing preliminary deliverables, such as project massing and orientations. These deliverables are compiled into documents, and after the conceptual design stage is tentatively completed, they are handed off to the structural and civil engineers. This transfer often results in delays and idle periods for the engineers, who must wait to receive the necessary documentation before beginning their own concept designs and generating their deliverables. Similarly, MEP engineers face delays as they, too, must wait for the architects' deliverables before they can commence their design process. Only after the teams have finalized their preliminary concept design, silos of information documents can then be shared in iterative feedback loops among the different teams to perform the necessary adjustments. Traditionally, the teams have to submit their information deliverables to the architects and owners for the design concept documents. If the design is rejected, which often occurs late in the process as it depends on the completion of all design inputs, structural/civil engineers, MEP engineers, and architects are required to make adjustments and rework their designs. This leads to several iterative cycles before the design is ultimately accepted. Once the owner approves the design, a finalized concept design report is prepared, enabling the project to advance to the schematic design phase. This phase proceeds in a similar manner as the concept design and includes several iterative and feedback loops, idle time and delays, rework and adjustments until the approvals of the architects and owners are received.

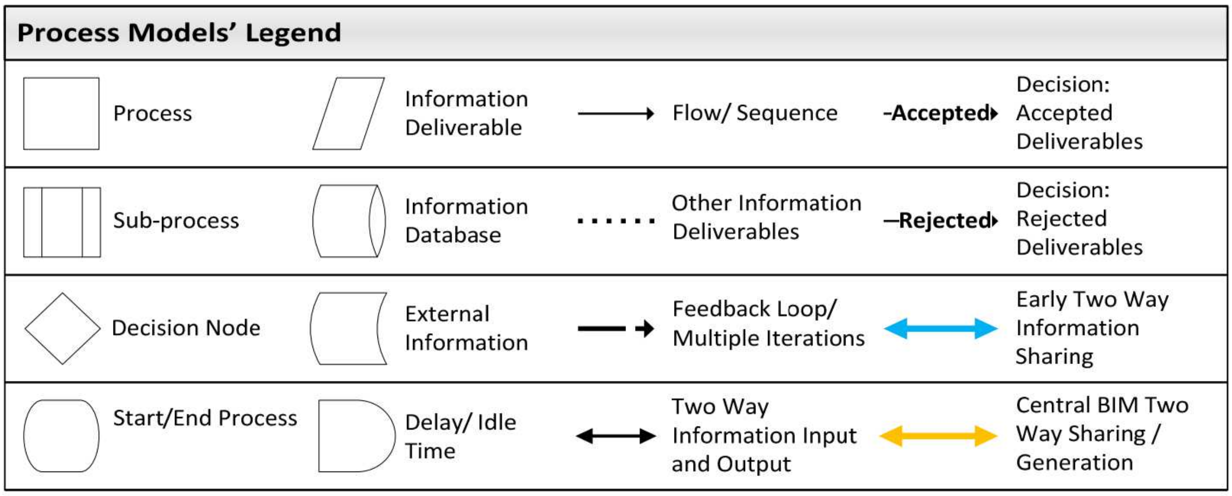


Figure 4.1: Components of the Process Models of the Traditional and BIM-based Design Phases, Al Hattab, 2013

This Diagram indicates that in traditional 2D CAD design, the different participants have to wait for each other's design completion; the data deliverables are piled in silos before they can be exchanged between the design teams. In such cases, data can become obsolete, in other words, the data goes to waste (Al Hattab, 2013).

This leads to the creation of Idle Time which is a large source of waste in design and is a critical factor to be eliminated to prevent delaying the design generation phase requested by the owner (Al Hattab, 2013).

Lack of owner involvement and value generation is another outcome of this inefficient flow of information. As it is shown, the owner's involvement can not be done unless each design phase is completely done. This creates communication and information sharing which leads to iterative loops and rework. When data is shared in untimely batches, it often circulates between various design participants through multiple iterations before the design deliverables are finalized and approved by the architect and owner. Rejection, which is a common occurrence in design workflows, necessitates reworking the deliverables. Since the deliverables are in 2D CAD, any adjustment of a certain concept or a drawing perspective, has to be reflected in all other trades/disciplines and views. (Al Hattab, 2013)

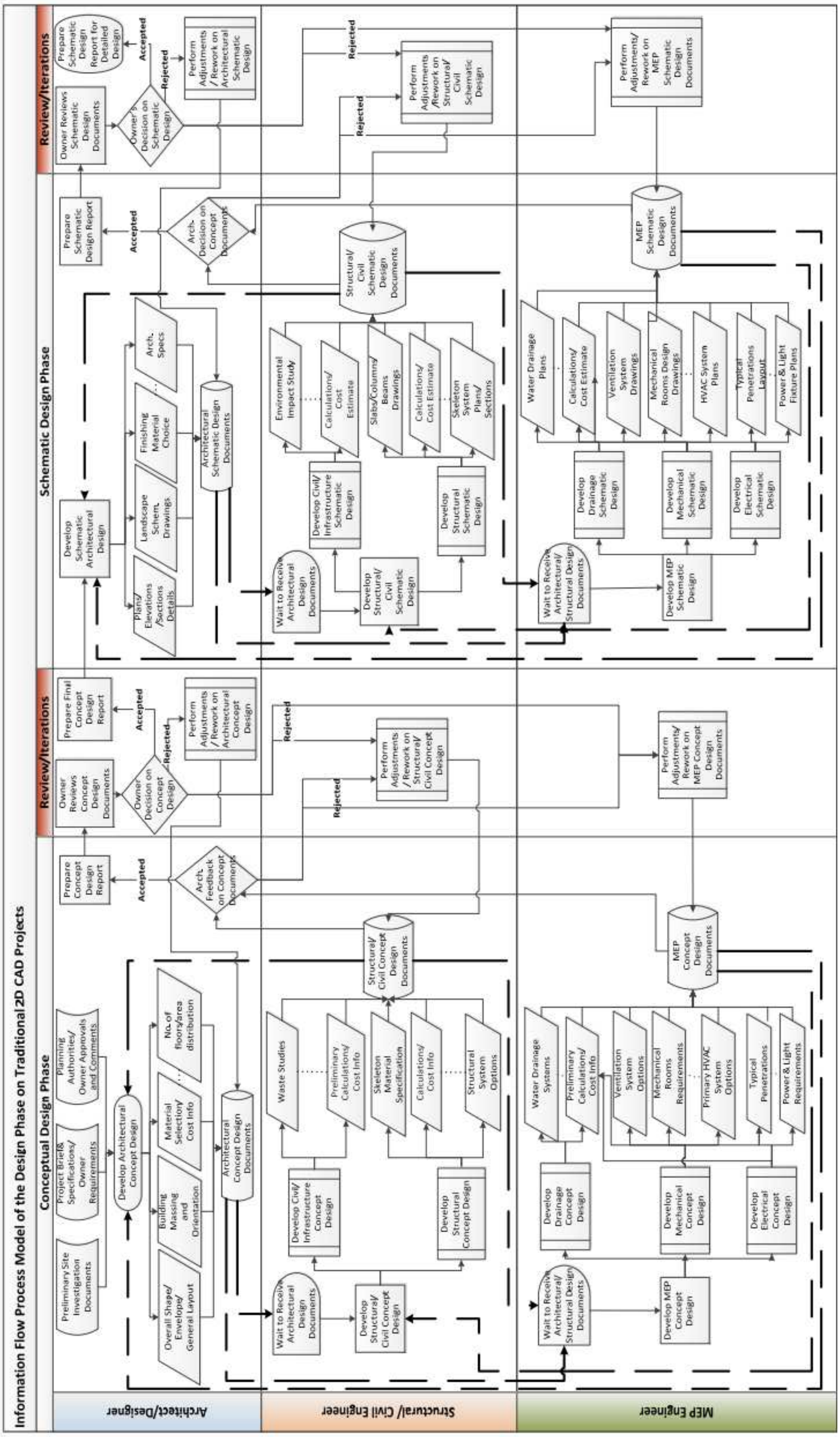


Figure 4.2: Information Flow Process Model of the Design Phase on Traditional 2D CAD Projects, Al Hattab, 2013

4.3 Problem, or Opportunity?

4.3.1 Identifying Gaps in Current Workflows

A more recent survey done by PlanGrid and FMI in April 2018 with nearly 600 construction leaders from around the world as participants also investigate:

- The activities that consume the most time during a typical workweek and their associated costs.
- The impact of poor data management and ineffective communication on projects, as well as the financial implications for the construction industry.
- The primary motivations for investing in construction-specific technologies and the factors that influence these investment decisions.
- Whether the implementation and use of technology align with the decision-making processes governing technology investments.

Here we will focus on the first three mentioned above to detect which phase of the AEC projects include the most wasted time, and money to indicate the need of efficient management and workflow introduced later on in this thesis.

In the first stage some activities in construction industry were grouped into six categories as mentioned below:

Optimal Activities

- Project execution and coordination

Acceptable Activities

- Interacting with external stakeholders
- Organizing people and the jobsite

Non-Optimal Activities

- Looking for project data
- Conflict resolution
- Dealing with mistakes and rework

When it was asked from the respondents how their time is spent, they indicated spending 11.2 hours on optimal activities including project execution and coordination. They're also spending 8.2 hours communicating with project stakeholders and 7 hours organizing the job site and people. Time spent on non-optimal activities included 5.5 hours looking for project data, 4.7 hours on conflict resolution and 3.9 hours dealing with mistakes and rework. This adds up to 14.1 hours spent on tasks that take construction professionals away from optimal activities.

Figure 4.3: Where is Time Being Wasted, PlanGrid & FMI, 2018

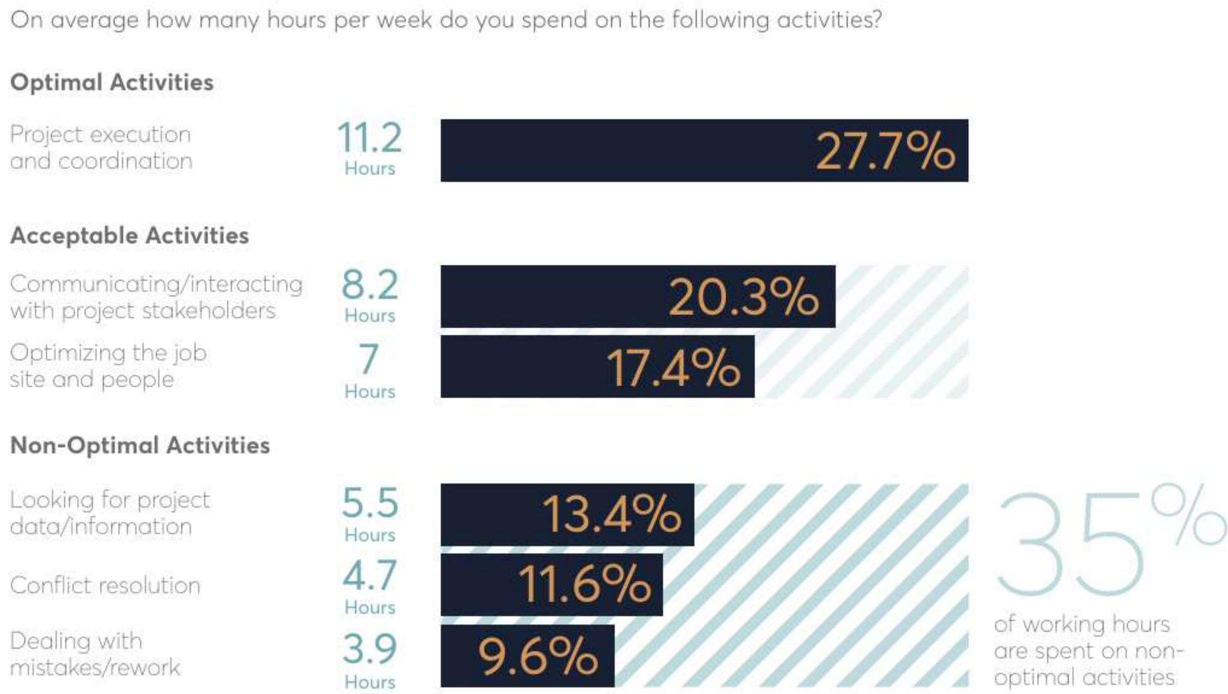


Figure 4.4: Average weekly hours spent on key construction activities, PlanGrid & FMI, 2018

With 40.5 total hours spent across all activities per week, each team member is spending 13.4% of their time looking for project data, 11.6% on conflict resolution and 9.6% of their time dealing with mistakes and rework. This means construction teams are spending an average of 35% of their work hours on non-optimal activities each week. In 2018, time spent on non-optimal activities such as dealing with mistakes and rework, looking for project data and handling conflict resolution will cost the US industry an estimated $177.5 billion in labor costs. Using known forecasting data for global construction spend, the worldwide cost of non-optimal labor activities can be predicted. Assuming a $10.5 trillion spend, the waste amounts to $1.4 trillion globally. While waste can never be entirely eliminated, the cost highlights the global opportunity available to those who focus on efficiency and process at every stage of construction.

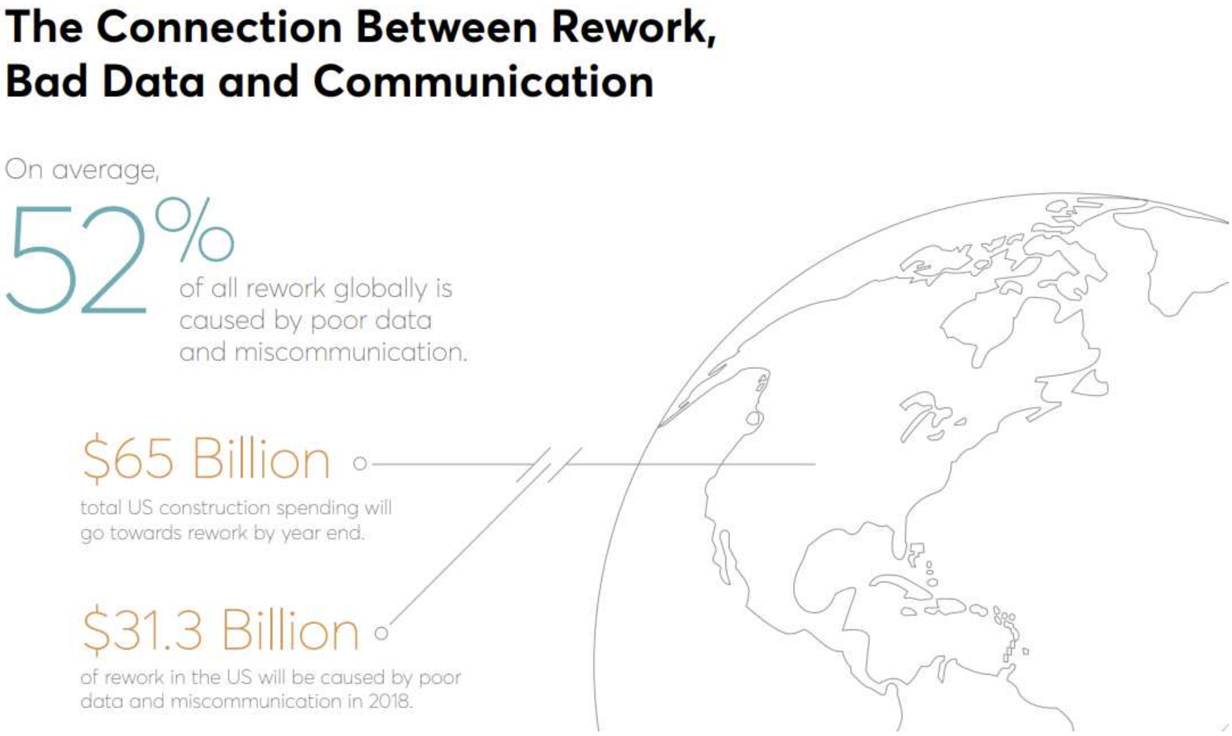


Figure 4.5: The Connection Between Rework, Bad Data and Communication, PlanGrid & FMI, 2018

The most common single selection for spending more time than expected on a task was poor communication among project stakeholders (23% of respondents). Regardless of the activity, when more time is spent than expected, the majority of respondents suggest it was due to inaccurate project data or difficulty accessing the information they need.

While many of the non-optimal activities that occur on a project site cannot be eliminated altogether, analyzing and improving the amount of time required is an essential goal in order for construction teams to be competitive and profitable in today's market.

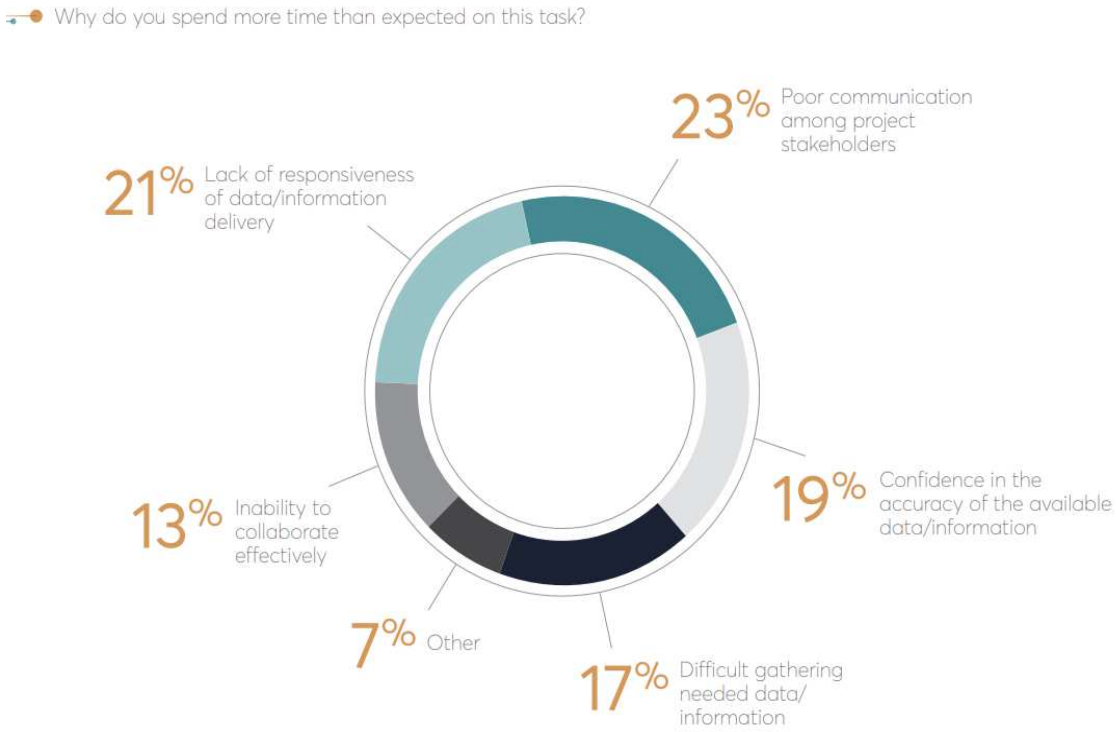


Figure 4.6: Reasons for exceeding expected time on tasks, PlanGrid & FMI, 2018

Effective communication and access to accurate project data are essential at every stage of construction. Ineffective data management and communication frequently lead to rework, which can result in significant long-term cost implications for both owners and developers. According to FMI, construction spending in the United States was projected to reach $1.3 trillion in 2018. With rework estimated to account for 5% of total construction costs, this equates to approximately $65 billion spent on rework during that year.

The survey found that in the US, rework directly caused by inaccurate, inaccessible and incompatible project data accounts for 48% of the total quantity of rework. Applied to the US industry at large, this cost is more than $31.3 billion annually. Globally, an average of 52% of rework was caused by poor project data and communication, representing a worldwide cost of $280 billion in 2018.

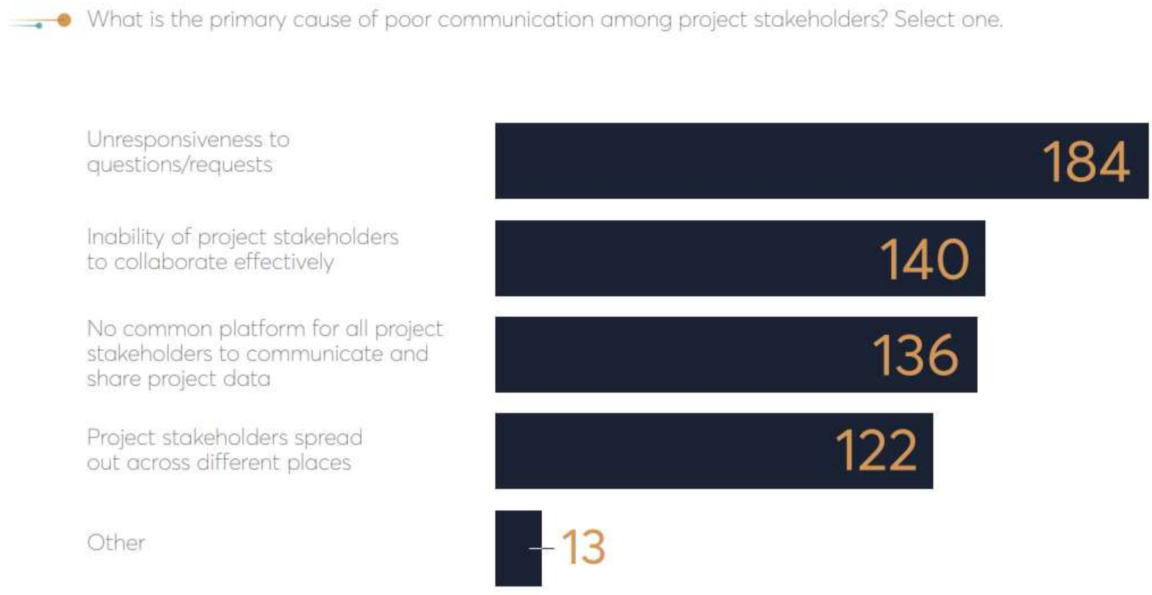


Figure 4.7: Primary cause of poor communication among stakeholders, PlanGrid & FMI, 2018

When asked what the primary cause of poor project data and information was, 34.4% chose erroneous or incorrect project data–meaning it was outdated or otherwise faulty, while 23.8% cited difficulty accessing needed project data. When construction firms are forming their technology deployment strategy, a top priority should be choosing tools that enable teams to more easily communicate and access accurate project data.

Figure 4.8: Primary cause of poor project data and information, PlanGrid & FMI, 2018

The reasons provided by participants for investing in construction-specific technology closely align with the challenges the industry faces regarding data integrity and accessibility. Beyond the primary goal of enhancing project productivity (cited by 57% of respondents), the top motivations for investment included achieving better access to project data (58% of respondents) and improving the accuracy of that data (56% of respondents). The alignment of these top motivations with the previously identified challenges is promising. Beyond the top three, the responses show alignment around the need to boost productivity, with only 7% indicating that they don't rely on industry-specific technology to build.

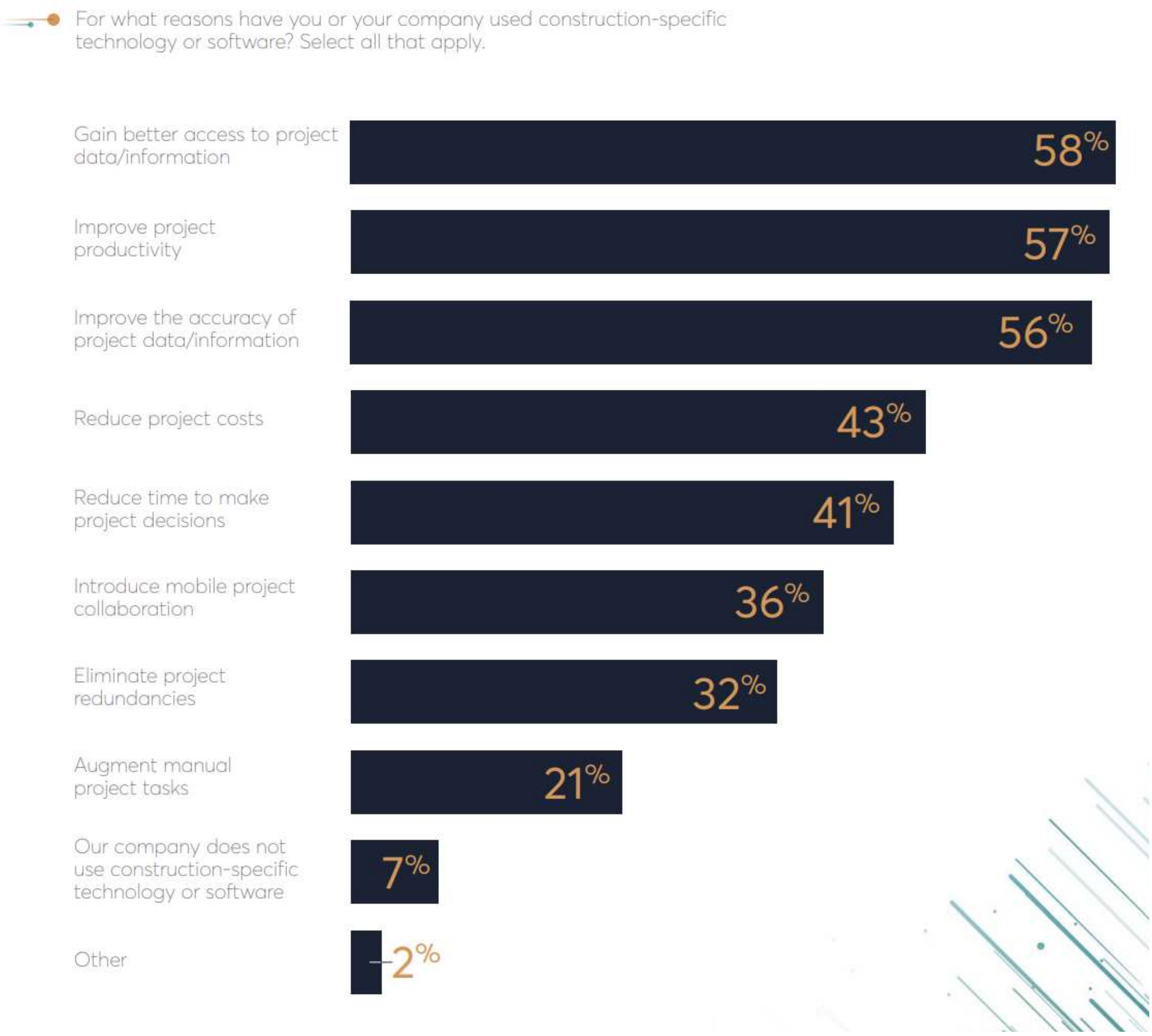


Figure 4.9: Primary reasons for adopting construction-specific technology or software, PlanGrid & FMI, 2018

4.3.2 Opportunities Offered by BIM for Enhanced Collaboration

These two studies clearly show the importance and need of correct and efficient information and data management in the AEC industry and how improving communication and investing in construction-specific technology can help improve the efficiency and reduce the costs and time spent on non optimal activities.

In the next part we will introduce BIM as a chosen solution for this information and data management and we will dive more deeply into the way that this workflow can help firms boost their efficiency. But before going into the small details and investigating deeply, first we need to know what BIM is and have more fundamental knowledge about it.

4.4 Definition of BIM

4.4.1 What is BIM? An Evolution in AEC Industry

According to Bimal Kumar (2015) BIM (Building Information Modelling) is an acronym that many people in the construction industry are becoming increasingly interested in. Right up front, here are some commonly held **misconceptions** regarding what BIM is:

- Viewing BIM as merely a piece of software.
- Believing that implementing BIM software will automatically result in over 20% cost savings.
- Assuming that purchasing software like Revit is sufficient to meet client demands for BIM usage.
- Claiming that BIM practices have existed for 30 years since the advent of Computer-Aided Design (CAD).
- Equating BIM with CAD as if it were simply a rebranding of the latter.

One of the most straightforward ways to define and understand an acronym is by breaking it into its individual components. In the case of BIM:

- **B** stands for **Building**, which can be understood both as a noun and a verb. As a noun, it refers to a constructed facility, such as a home, office, or commercial space. However, Bimal Kumar (2015) argues that the verb form—emphasizing the process of constructing—is more relevant in this context.
- **I** stands for **Information**, representing raw data organized in a way that delivers meaningful insights.

- **M** stands for **Modeling**, which refers to the process of representing or describing something—whether physically or conceptually—to facilitate a deeper understanding.

Some of the definitions of BIM provided by different people in this book are worth to be mentioned and investigated, here are a selection of them shown below:

1- BIM is defined as a modeling technology and an associated set of processes aimed at producing, communicating, and analyzing building models. These models are characterized by: (Eastman et al., 2011):

- Building components represented with intelligent digital elements that 'know' their identity and can carry computable graphic attributes, data attributes, and parametric rules.
- Components that include data on behavior, supporting processes such as quantity take-off, specifications, and energy analysis.
- Consistent and non-redundant data, ensuring that changes to component data are reflected across all views of the model.
- Coordinated data, guaranteeing that all representations of the model remain in sync.

2- Paul Morrell (ex-Chief Construction advisor to the UK Government) believes that BIM is about 'the intelligent use of digital data to design, construct, manage and use a built facility' (as quoted in AEC Magazine, 2012).

3- The National BIM Standards – United States definition is "BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward" (NBIMS, 2013).

4- A slightly different way of looking at BIM, particularly in relation to CAD, is that BIM contains syntax (geometry, topology) as well as semantics (meaning, while CAD only includes syntax. Therefore, semantics is what gives BIM the additional power and strength to be able to facilitate things that CAD cannot. Semantics, in this context, is simply the meaning provided by the additional information attached to every element in a building information model. (Kumar, 2015)

Each definition underscores different aspects of BIM, from its technological underpinnings and data integration to its role in fostering intelligent decision-making throughout a facility's lifecycle. Together, these perspectives highlight the transformative potential of BIM in the AEC industry.

4.5 Benefits of BIM

After getting a basic knowledge about what BIM is, now it is time to investigate more about how BIM can become helpful in our tasks and become handy in managing the information existing in the AEC industry projects.

Bimal Kumar (2015) refers to one of the key ideas behind using the BIM tool which is significantly important in optimising not only the design process but also the construction phase and beyond that. This idea is building the asset twice, once digitally and fixing all constructability and design related issues before building it physically on site. Then he refers to the clash detection and automatic modification of drawings after changing elements of design and consistency among all the dimensions and labelling in a model due to parametric modelling.

Regarding the clash detection which is considered as one of the earliest and fundamental examples of using BIM, a figure is used to indicate a clash between a structural beam and the lift shaft which can be detected easily and fixed quickly by a BIM software.

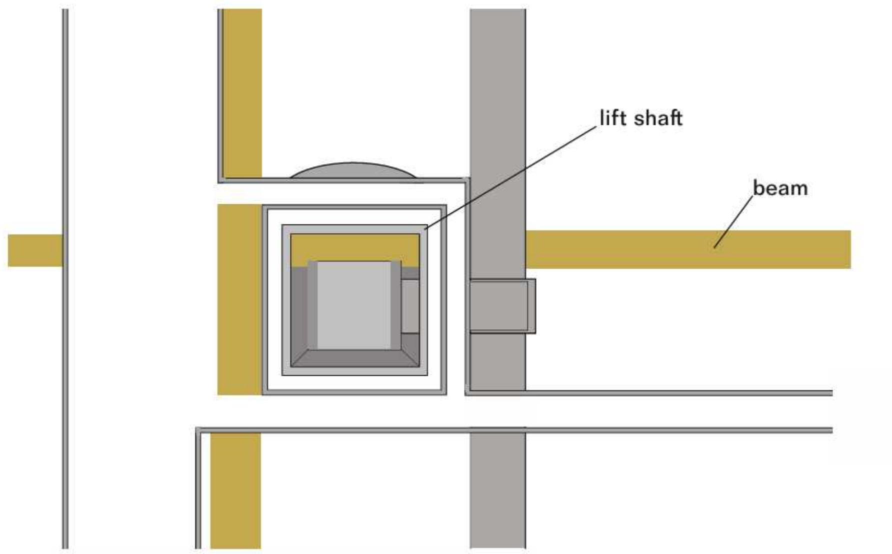


Figure 4.10: An example of clash detection between a lift shaft and beam, Kumar, 2015

Here is the list of the most commonly used applications of BIM technologies (Kumar 2015, Xiaoning Gang, 2024):

- Model Visualization and Virtual Simulation
- Data Integration and Collaborative Design
- Information Sharing and Communication Collaboration

- Optimization of Project Management which includes:
    - Material and Cost Estimation
    - QuantityTake-Offs
    - Clash Detection
    - Consistent Drawings

4.5.1 Model Visualization and Virtual Simulation

Model Visualization and Virtual Simulation use computational software to enhance architectural design processes. Model visualization provides dynamic, 3D views of designs, allowing teams and clients to explore proposals early and identify potential issues. Virtual simulation goes further by testing designs against real-world conditions, such as natural disasters or climate changes, to ensure durability and performance. Through BIM technology, these tools improve design accuracy, reduce risks, and cut costs. In practical projects, they enhance client engagement and optimize factors like energy efficiency by simulating energy consumption and material configurations, transforming the construction industry.

4.5.2 Data Integration and Collaborative Design

Using BIM technology transforms architectural workflows by integrating all project data into a single, unified model that is accessible to all stakeholders. Real-time updates ensure that any design changes are immediately reflected, minimizing errors and rework. BIM enables global collaboration, allowing designers from various countries to work on the same model at once, enhancing flexibility and efficiency in international projects. This feature allows for real-time discussions and adjustments, boosting both productivity and design quality. Additionally, BIM's integration and collaborative features provide powerful visualization tools, such as 3D models, which help clients intuitively understand the design and detect potential issues early. Advanced tools like daylighting and energy simulations further support sustainable, high-quality design by improving client understanding and addressing issues ahead of time.

4.5.3 Information Sharing and Communication Collaboration

Information Sharing and Collaborative Communication are crucial for transparent and efficient project execution. BIM technology provides a centralized, multidimensional platform where all project data—such as design plans, material specifications, and construction progress—is digitally stored and shared. This enables real-time data synchronization across all team members, unlike traditional fragmented communication methods like emails or calls.

For example, structural changes made by a designer are immediately visible to all stakeholders, ensuring decisions are based on up-to-date information. BIM also allows for simulations of potential construction scenarios, such as material supply adjustments or safety concerns, enabling pre-construction problem-solving and reducing errors, delays, and costs. Furthermore, BIM enhances coordination among disciplines like structural, electrical, and plumbing engineering by providing a unified model for input sharing, fostering interdisciplinary collaboration and innovation. This comprehensive approach improves efficiency, safety, and project outcomes.

4.5.4 Optimization of Project Management

Project management optimization involves improving the planning, execution, monitoring, and completion of construction projects through advanced technologies and methodologies. It enhances project efficiency, quality, and client satisfaction while ensuring timely, budgeted completion. BIM technology plays a key role in this optimization by providing a collaborative platform for the design team, reducing data inconsistencies and information silos. Unlike traditional 2D drawings, BIM offers real-time, multidimensional updates that help manage design and construction processes. It enables early detection of design conflicts, improving cost and time efficiency, and enhances safety by simulating construction processes to identify potential risks. BIM also allows for continuous project monitoring and post-maintenance support, with real-time tracking of progress and costs. After project completion, BIM can transform into digital twins, offering valuable resources for future building operation and maintenance.

Other applications and benefits are mentioned in various studies such as:

- Application of BIM in Sustainable Building Design
- Application of BIM in Digital Construction
- Integration of BIM with Intelligent Buildings and Internet of Things
- Building Automation and Machine Learning
- Integration of Architecture and Urban Planning

As these applications are not in the scope of this study, we will not dive into their details, but if you are interested to find out more about these you can take a look at the paper done by Xiaoning Gang (2024).

4.6 BIM-Based Design Phase Process Model

Since we demonstrated the 2D CAD traditional workflow in the previous parts and we analyzed why and how this inefficiencies exist in this workflow, it is worth to talk also about the BIM workflow and a comparison between these two, to be able to have a more general view over this workflow and understand better the process. A swim-lane diagram exactly like the one used for 2D CAD workflow was illustrated by Al Hattab M. (2013) to demonstrate this process. This diagram is divided horizontally as well as the previous one; however, vertically only the conceptual and schematic design phases are present as the information coordination, sharing, and owners' feedback happen during each of these phases and do not have to wait till the design is complete.

The concept design phase starts by developing the architectural concept in the BIM environment and generating deliverables that are incorporated into the building information model. Unlike the traditional 2D CAD design phase, the structural/civil and MEP engineers do not have to wait until the completion of the architectural design concept to proceed. Instead, data can be shared early and efficiently before being fully completed, allowing the three cross-functional teams to simultaneously develop their design concepts. These concepts are created within the BIM environment, resulting in individual, detailed building information models that are later combined into a single, centralized model. This central model and individual models allow two-way information sharing between the different design participants in real-time as well as prompt adjustments of the model information after integrating and coordinating all the data. In addition, the owner can get on board during the design concept development to provide his early feedback on the design criteria as the required deliverables can be extracted from the building information models at any time. This avoids the late "acceptance or rejection" decisions which result in massive time and cost consuming rework and countless design iterations as it happens on projects not using BIM. Once the conceptual design phase is completed, it is unnecessary to start from scratch to develop the schematic design process. Instead, the existing individual building information models are refined and enhanced to meet the required Level of Development (LOD) for the schematic design phase. This approach eliminates redundant efforts and saves time. The schematic design process then continues seamlessly, following the same logic as the conceptual design phase (Al Hattab, 2013).

In contrast with the traditional 2D CAD workflow, in BIM-based design, early and timely exchange of incomplete information between participants is enabled by sharing and integrating the building information models of the teams at any point in time. This allows real-time design adjustments and development. The information is then always up-to-date, and the clear design intent visualization facilitates communication between players and allows for continuous information flow instead of interrupted batch flow (Al Hattab, 2013).

The swim-lane diagram of BIM-based design phases clearly illustrates how delays are significantly reduced compared to traditional design phases. Because data sharing can occur even before the design is fully finalized, teams experience minimal or no idle time while waiting for complete data from one another. Idle time, which is a major source of inefficiency in the design process, is a critical issue to address to avoid delaying the generation phase requested by the owner. By leveraging BIM, these idle periods and unnecessary waiting times are effectively minimized or entirely eliminated (Al Hattab, 2013).

BIM facilitates the continuous involvement of the owner or the owner's representative throughout the design process by allowing them to extract design information as needed from integrated or individual models. This early and ongoing feedback is highly valuable, as it prevents late decisions on design data, which could otherwise lead to rework, wasted costs, and delays. Furthermore, by engaging the owner consistently during the progression of the design, their input and value propositions are accurately reflected and effectively integrated throughout the project lifecycle (Al Hattab, 2013).

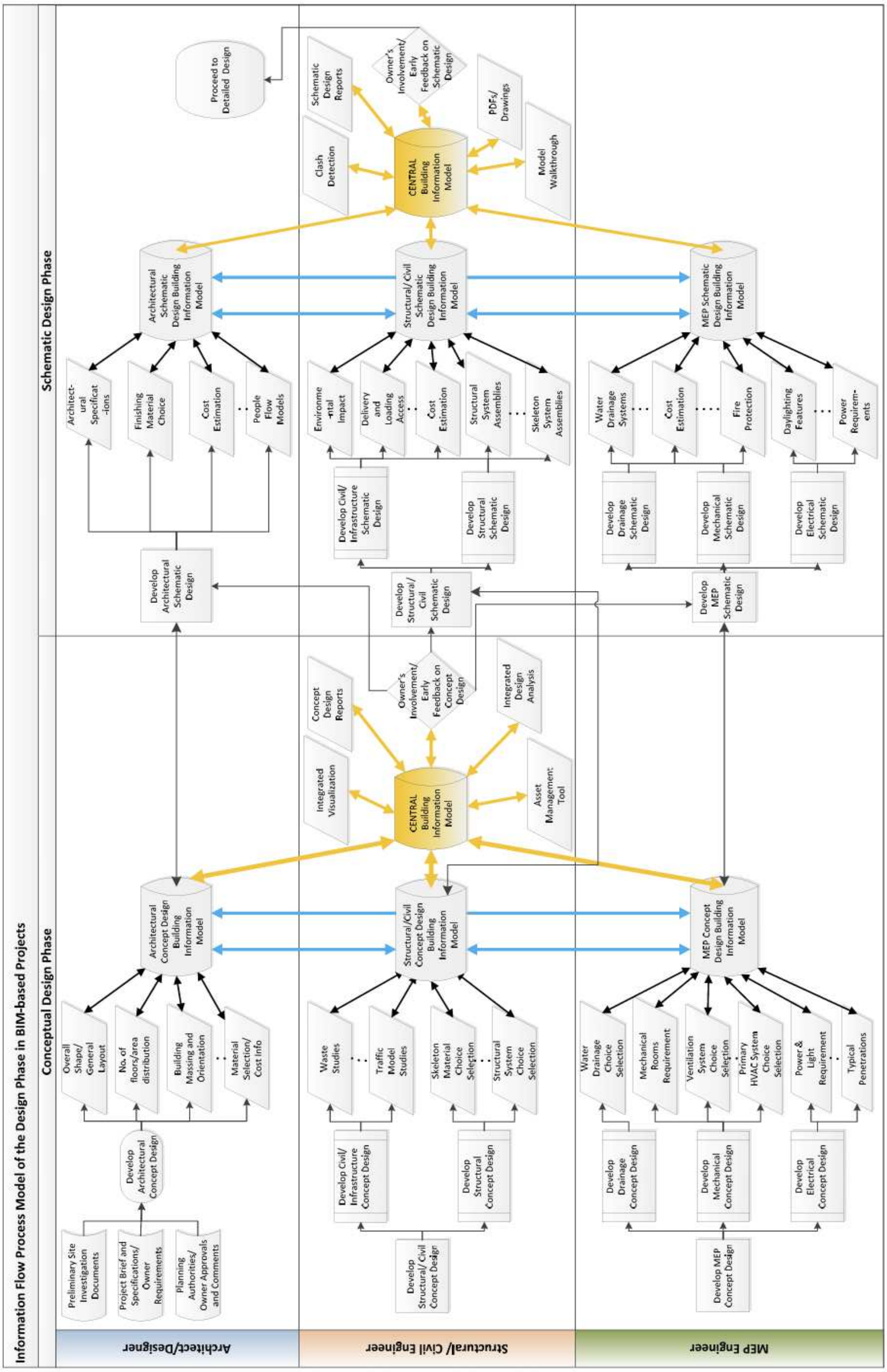


Figure 4.11: Information Flow Process Model of the Design Phase in BIM-based Projects, Al Hattab, 2013

In traditional 2D CAD workflows, adjustments to a concept or drawing perspective require manual updates across all related trades, disciplines, and views. In contrast, BIM streamlines this process by automatically updating all views and elements in response to a single modification, while notifying involved stakeholders of necessary adjustments in real-time (Hardin, 2009). This capability significantly reduces negative iterations and rework, saving time and avoiding cost overruns (Al Hattab, 2013).

BIM also empowers designers to explore alternative concepts, conduct value engineering, and optimize designs. By fostering collaboration among participants, BIM enables data input from all stakeholders, creating a comprehensive representation of the owner's design intent. This shared understanding allows architects and engineers to work towards a unified, higher-quality design, avoiding the fragmented and inefficient processes typical of traditional iterative workflows (Al Hattab, 2013).

The process models can be used as a source of data for other tools and applications to manage the design phase of construction projects in terms of cost, time, and resources. To quantitatively assess the effectiveness of design management and to measure potential time and cost savings realized from the use of BIM on projects, the authors will further develop simulation models. These models transform the static process models into dynamic models where the user can immediately observe the changes with time advancement and while interacting with the model (Baldwin et al., 1999).

4.6.1 Concept of Interoperability in BIM Workflows

4.6.1.1 Introduction to Interoperability

The architecture, engineering, and construction (AEC) industry relies heavily on collaboration between diverse workgroups to achieve project goals and ensure efficient processes (Olsen, 2022). However, no single software solution or platform can encompass all the different requirements of a multidisciplinary construction project. This limitation often results in inefficiencies in design and construction processes. Building Information Modeling (BIM) offers a methodology that integrates digital tools, processes, and technologies, enabling the coordinated handling of project information.

A critical aspect of BIM is **interoperability**, which ensures the seamless exchange of data between software platforms. Interoperability allows data created in one application to be accessed, interpreted, and utilized effectively in another, fostering collaboration and reducing inefficiencies. According to the National Institute of Building Sciences (NIBS, 2008) and Teicholz et al. (2008), interoperability involves enabling software and hardware on multiple platforms from various vendors to exchange meaningful and useful information.

Interoperability is achieved through open standards, such as those managed by buildingSMART International, which promotes standardized data exchange protocols. These standards, including Industry Foundation Classes (IFC), ensure that BIM data can be utilized across diverse applications without data loss. This capability extends beyond graphical representation to include attributes like materials, costs, timelines, and sustainability properties, which are critical for comprehensive project management.

4.6.1.2 The Importance of Interoperability

Interoperability is vital for enabling seamless collaboration in multidisciplinary projects. For example, a structural engineer using one software tool can share their designs with an architect working on another platform. This reduces communication barriers, ensures consistent updates across disciplines, and improves efficiency. Additionally, interoperability supports the lifecycle management of BIM data, allowing information to remain accessible and useful from design to construction and facility maintenance (Teicholz et al., 2008).

4.6.1.3 Technical Implementation of Interoperability

Technically, interoperability in BIM workflows relies on schema languages and open, publicly managed data formats. A schema organizes data formally, enabling it to be exchanged and interpreted between applications (Sawhney, 2014). While interoperability varies depending on the design process and software used, tools produced by the same company, such as Revit and Navisworks, typically exhibit strong compatibility.

4.6.1.4 Approaches to Achieving Interoperability

1. **Open Standards and Formats:** IFC, developed by buildingSMART International, allows different platforms to share and interpret data effectively. BIM models created in Revit, for instance, can be exported as IFC files and imported into Navisworks without data loss.

2. **Standardized Libraries and Protocols:** Standards like the NBS BIM Object Standard provide guidelines for creating reusable BIM objects that operate seamlessly across projects (Hardin & McCool, 2015).

3. **Cloud-Based Solutions:** Platforms like Autodesk Construction Cloud enhance interoperability by serving as centralized repositories for real-time data sharing, reducing the need for multiple software licenses (Hardin & McCool, 2015).

4. **Data Exchange Formats:** Common formats include proprietary ones like DWG and RVT, open formats like IFC and COBie, and XML-based structures for specialized workflows (Teicholz et al., 2008).

4.6.1.5 Challenges and Opportunities

Despite the advancements, interoperability challenges remain due to proprietary software limitations and inconsistent data standards across regions. These challenges necessitate continued efforts from software developers, standardization bodies, and stakeholders to improve the seamless integration of tools and processes. For example, while tools like Revit and Navisworks from Autodesk exhibit strong interoperability, combining them with external tools may still require significant manual adjustments or adherence to open standards like IFC.

Emerging technologies, such as digital twins and AI-driven design optimization, heavily rely on interoperable systems to maximize their potential. These innovations present opportunities for the AEC industry to achieve a more integrated approach to design and construction, further reducing inefficiencies and improving outcomes (Hardin & McCool, 2015).

Interoperability is the cornerstone of effective BIM workflows, enabling real-time collaboration, reducing costs, and improving project outcomes. By adopting open standards like IFC, leveraging cloud-based solutions, and enhancing compatibility across platforms, the AEC industry can transition to more integrated workflows. However, achieving full interoperability requires continuous development and collaboration among software developers, industry stakeholders, and regulatory bodies. As Osello (2012) emphasizes, BIM's success as a transformative tool hinges on its ability to facilitate efficient data exchange across diverse applications, ensuring a comprehensive and cohesive approach to project execution.

4.6.2 BuildingSMART and OpenBIM: Exchange Formats (IFC, COBie, etc.)

4.6.2.1 Introduction

BuildingSMART International plays a pivotal role in advancing data exchange technology within the architecture, engineering, and construction (AEC) industry. As an organization committed to standardizing workflows, processes, and procedures for Building Information Modeling (BIM), BuildingSMART champions the development and adoption of open standards. These standards aim to ensure seamless interoperability among diverse BIM software platforms, enabling efficient collaboration across project teams. BuildingSMART's key initiatives include the creation and promotion of three fundamental standards: Industry Foundation Classes (IFC), International Framework for Dictionaries (IFD), and Information Delivery Manual (IDM), all of which are recognized by the International Organization for Standardization (ISO).

4.6.2.2 Key Data Exchange Formats

1. Industry Foundation Classes (IFC): The IFC format is the most widely used standard for data exchange in BIM environments. It is an object-oriented, structured data model that supports the classification and description of building elements beyond geometric or physical attributes. For example, IFC can encapsulate details about materials, quantities, costs, and construction sequences, making it invaluable for ensuring interoperability across software platforms (BuildingSMART International, 2013).
   Model View Definitions (MVDs):
   To address the diverse needs of users, IFC includes Model View Definitions (MVDs). These provide a framework for specifying which pieces of information are necessary for particular tasks or stages of a project. For instance, MVDs can define what data should be included in a contract or validation model, ensuring clarity and consistency in data exchange (Steel et al., 2012).

2. International Framework for Dictionaries (IFD): The IFD standard focuses on providing a universal dictionary for BIM objects, enabling precise and consistent definitions for building components. This standard ensures that terms used in BIM processes are understood uniformly across different software tools and project stakeholders.

3. Information Delivery Manual (IDM): The IDM standard supports the formalization of workflows by defining which information should be exchanged at specific project milestones. This ensures that all stakeholders have the necessary data to perform their tasks efficiently, reducing redundancy and improving project coordination.

4.6.2.3 Levels of Interoperability

As outlined by Steel et al. (2012), interoperability in IFC operates on four levels:

1. File-Level Interoperability:
   The ability of different tools to exchange files successfully, ensuring data is transferred without loss.

2. Syntax-Level Interoperability:
   Ensures that files are parsed correctly, with no errors, and allows tools to interoperate effectively.

3. Visualization-Level Interoperability:
   The capability of tools to correctly visualize the exchanged model, ensuring that the graphical representation remains accurate.

4. Semantic-Level Interoperability:
   Focuses on the shared understanding of the exchanged data's meaning. This is critical for ensuring that tools interpret the data consistently.

Despite these advancements, challenges persist due to the diverse nature of the construction industry. Projects vary significantly in scope, ranging from small residential buildings to complex infrastructure like airports. This variability has made it difficult for any single tool to implement all aspects of IFC comprehensively, leading to fragmented interoperability in practice (Steel et al., 2012).

4.6.2.4 Practical Applications and Benefits

By adopting open standards like IFC, the AEC industry can achieve:

- Improved Collaboration: Stakeholders can work on shared models without being restricted by proprietary software limitations. For example, an architect working in Revit can share data seamlessly with an engineer using Tekla through IFC.

- Data Consistency: MVDs ensure that all parties receive the information required for their specific roles, reducing errors and miscommunications.

- Lifecycle Integration: IFC supports the exchange of data throughout a building's lifecycle, from design to operation and maintenance, enhancing long-term project value (BuildingSMART International, 2013).

BuildingSMART and its OpenBIM initiatives have established a foundation for achieving interoperability in BIM workflows. Through standards like IFC, IFD, and IDM, the organization has provided tools to address the complexities of data exchange in the AEC industry. While challenges remain, ongoing efforts to improve interoperability hold the promise of transforming BIM into a fully integrated and collaborative framework, enabling projects to be completed more efficiently and effectively.

4.6.3 Key Components of BIM: Elements, Families, Types, and Instances

In Revit, the primary software utilized throughout this thesis, the BIM environment employs a hierarchical framework to organize all elements within the model. This hierarchy facilitates multi-level workflows, enabling a higher degree of detail and more effective information management within the model. The classification system serves multiple purposes, depending on the specific goals of the model. Every object in a Revit project adheres to this hierarchy, which is structured as follows: Elements, Families, Types, and Instances. This classification is crucial because each object has parameters associated with each of these levels.

- Categories or Elements: Every object in a project is assigned to a category, which represents the broadest level of classification. Categories group objects based on their general type, regardless of specific properties such as dimensions or materials. For instance, all doors in a project fall under the "Door" category, regardless of their unique characteristics.

- Families: Within a category, elements are further divided into families, which group objects with similar geometric characteristics and shared properties. Families consist of elements that may differ in specific values but share a common set of properties. There are three types of families:
  - System Families: These are predefined by Revit and cannot be deleted. System families include built-in components of the software, but users can duplicate and modify them to create new families based on these templates.
  - Loadable Families: These families include components such as doors, windows, and furniture—items that are typically installed as finished products in a construction project. Loadable families can also represent system components like HVAC or plumbing installations. Users create or edit these families in Revit's family editor and save them as .RFA files, which can be loaded into projects.
  - In-Place Families: These families are created directly within a project using tools similar to those for loadable families. They are generally used for unique elements that are unlikely to be reused or copied. Unlike other families, in-place families do not allow for the creation of multiple types.
- Types: Types are subdivisions within families and are defined by specific parameter values. Multiple types can exist within a single family, distinguished by variations in parameter settings. Objects with identical parameter values are grouped under the same type.
- Instances: Instances represent the most granular level of detail for an object and are determined by the specific placement of the element within the model. For example, an instance parameter for a window might include its exact position relative to the wall hosting it.

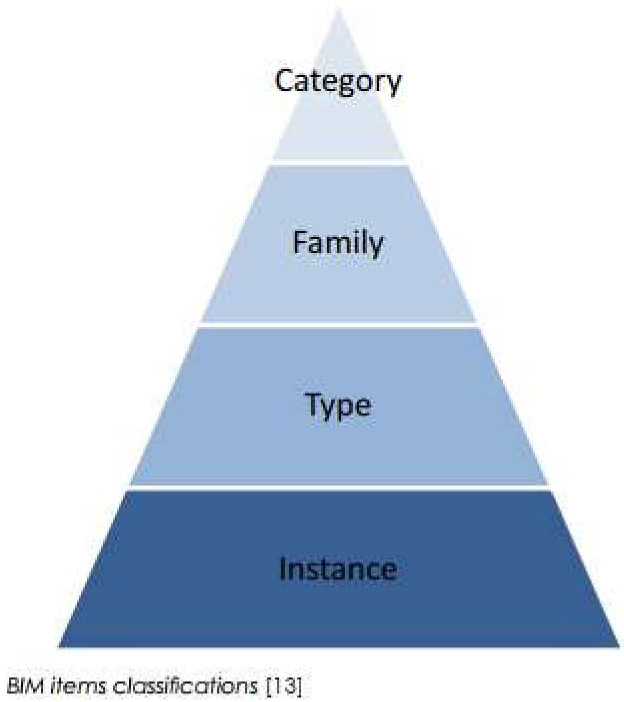


Figure 4.12: Working with Revit architecture, Osello, University lesson slides

4.6.4 Parameters: Shared, Project, and Global Parameters

In Revit, three main types of parameters are commonly used in a project: shared parameters, project parameters, and global parameters. These can be associated with either a type or an instance:

- **Shared Parameters**: These parameters are independent of any specific project or family and are managed through an external text file. This independence allows them to be shared across multiple projects and used by different stakeholders. Shared parameters are particularly useful for projects that consist of multiple files, ensuring consistency by avoiding the need to recreate parameters repeatedly. When shared parameters are used across files, the software can recognize them for various purposes, streamlining workflows in collaborative environments.

- **Project Parameters**: These parameters are created within a specific project and are not transferable between models. They are typically used in projects where the user does not anticipate reusing the parameter in other contexts. Project parameters are ideal for single-project applications or cases where the scope is well-defined and isolated.

- **Global Parameters**: While similar to project parameters, global parameters differ in that they are not applied directly to elements within the project. Instead, they are used to define project-wide characteristics, such as setting a specific value for a dimension or establishing relationships between properties. For example, global parameters can automate repetitive tasks, such as assigning consistent offset values to beams under a floor. By defining a global relationship, the software can apply these values automatically, saving time and improving accuracy.

4.7 BIM In Use

The buildingSMART International survey, titled "Understanding the Role of BIM and CDEs Today and Expectations for the Future," as part of the buildingSMART Virtual Summit was done on October 2021 with 250 responses collected from different AEC organizations with the aim of finding interesting correlations and results that reflect the current use of BIM and CDEs (Common Data Environments) today, and look at the role they will play in the future. The survey, conducted in collaboration with Oracle Construction and Engineering, primarily gathered responses from Europe and the Americas. It included organizations of various sizes, with those employing over 500 individuals forming the largest group. Approximately 75% of the respondents reported serving both private and public sector clients.

The survey revealed that 77% of respondents consider a common data environment (CDE) to be the most effective method for exchanging large volumes of information. Additionally, 53% of organizations reported an increased reliance on cloud-based solutions for project management over the past two years. Nearly half of the participants indicated that BIM is implemented in 76% to 100% of their projects, with 23% stating that BIM processes are used across all their projects.

According to the bSI report, BIM is progressively extending its applications beyond the design and construction phases to encompass downstream stages of the project lifecycle, including handover, operations and maintenance, as well as decommissioning and reuse.

Then it was asked from the participants about the main reason their company is currently using BIM. The top five reasons of using BIM were:

- Accelerating the identification and resolution of quality issues while eliminating clashes to improve design quality.
- Enabling a collaborative project environment for all stakeholders from inception to completion by providing a single source of information.
- Enhancing understanding and visibility of design decisions.
- Lowering design and construction costs.

- Ensuring the completeness and accuracy of construction handover information.

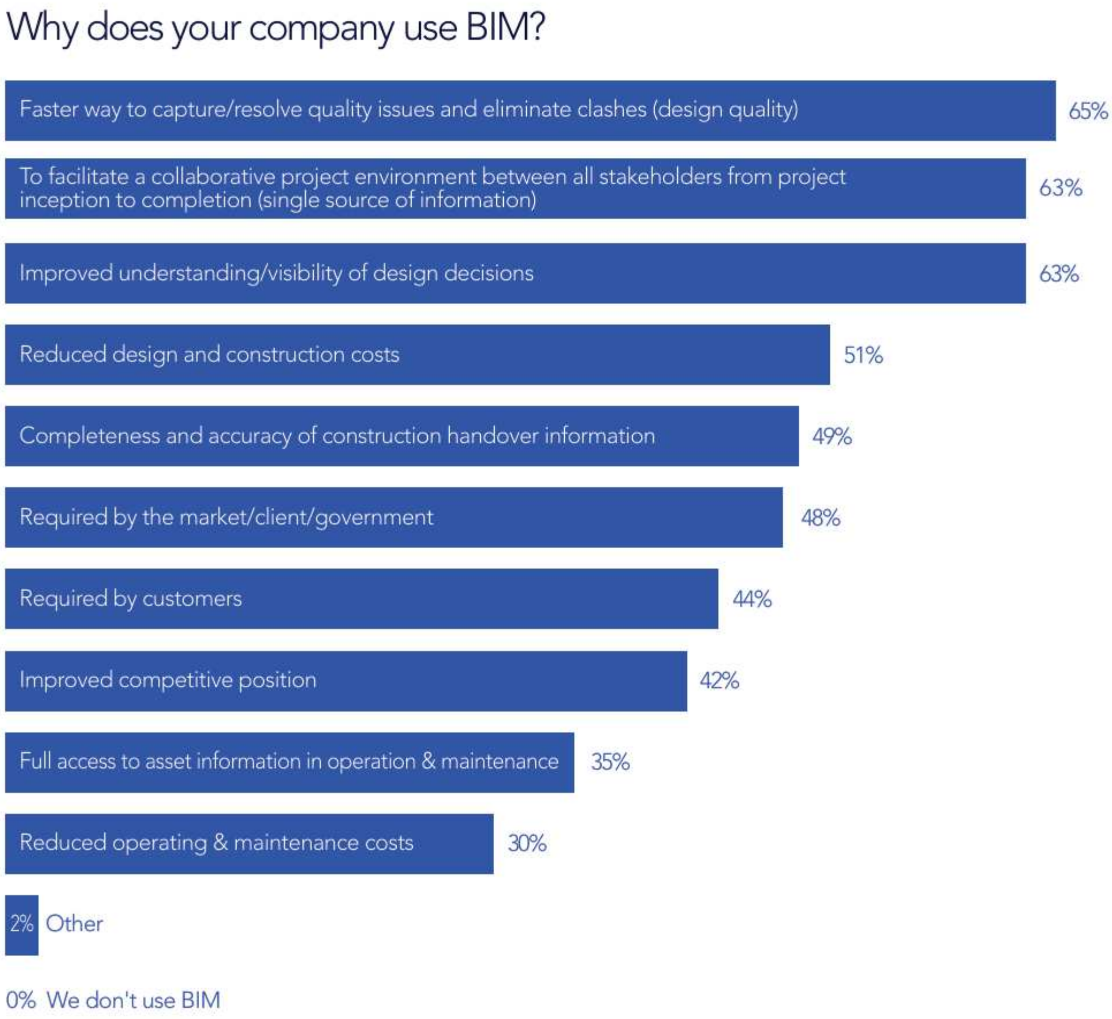


Figure 4.13: Reasons of BIM usage, BuildingSMART International, 2022

As a result, according to the survey, the top three optimized processes in those companies are:

- Accelerated resolution of quality issues and elimination of clashes (65%).
- Facilitating a collaborative project environment for stakeholders throughout the project lifecycle, from inception to closeout (63%).
- Enhanced understanding and visibility of design decisions (63%).

Additionally, more than half of respondents (51%) highlighted reduced design and construction costs as a key benefit, while 63% emphasized improved visibility and understanding of design decisions.

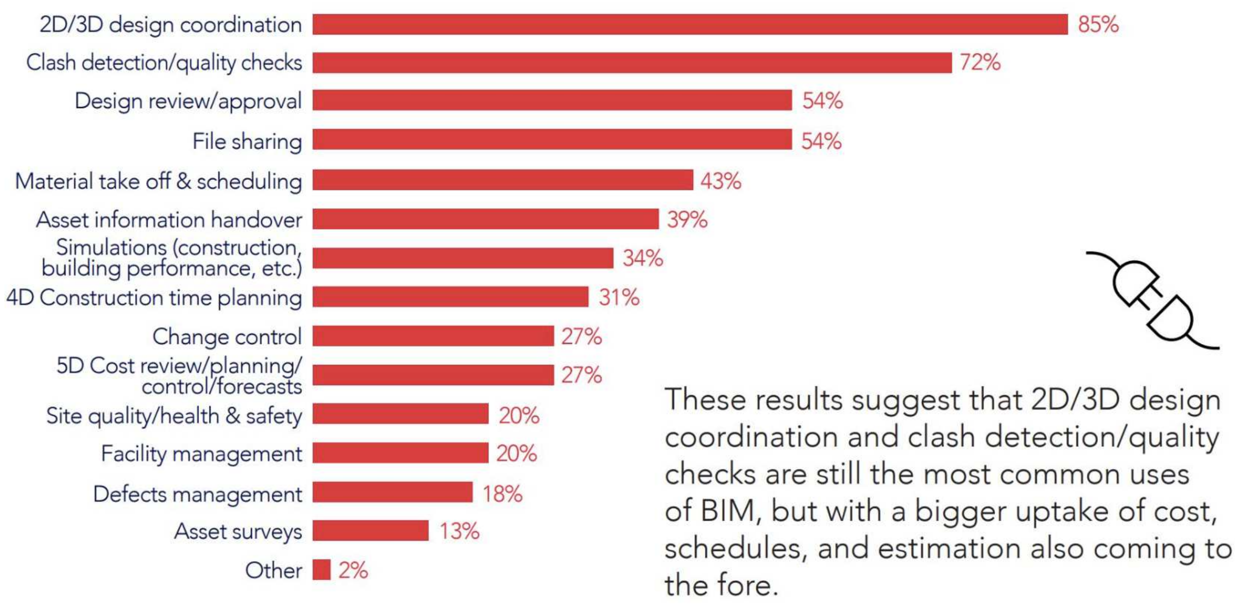


Figure 4.14: Most common BIM applications in AEC projects, Mercer, 2022

When it was asked to name the leading processes that are optimized for BIM within their organization, 85% of respondents cited 2D/3D design coordination, while clash detection and quality checks were named by 72%, and design review/approval and file sharing both came in at 54%. The bSI report also notes that survey data indicates growing adoption of BIM workflows.

When respondents were asked to identify the key processes optimized by BIM within their organizations, 85% highlighted 2D/3D design coordination as the leading benefit. Additionally, clash detection and quality checks were cited by 72%, while design review/approval and file sharing both received 54%. The bSI report further notes an increasing adoption of BIM workflows.

Regarding how BIM benefits their organizations the most, respondents pointed to improved decision-making (71%), enhanced quality (71%), and faster/better collaboration (70%) as the top advantages. Other notable improvements included increased transparency (57%) and reduced inefficiencies (49%).

Looking ahead, more than three-quarters of respondents (77%) identified error reduction and quality improvements as the most anticipated benefits of BIM. Other frequently mentioned future benefits included digital twin applications (66%), automation (64%), and cost reduction (52%).

This survey provides encouraging insights from a global audience, as highlighted by Aidan Mercer, marketing director at buildingSMART International. It demonstrates the widespread adoption and benefits of BIM across the entire lifecycle of projects and assets. According to Mercer, the findings emphasize how BIM and Common Data Environments (CDEs) add value in numerous areas, enhancing collaboration and coordination while building confidence among stakeholders.

More than three-quarters of respondents reported using a CDE or collaboration platform for sharing and exchanging large volumes of data in their daily work, with cloud technology enabling this shift. Respondents noted a significant transition toward cloud infrastructure, describing it as a “major shift in their focus and delivery,” further confirming the critical role of CDEs in supporting digital transformation across organizations.

Frank Weiss, senior director of new products, BIM and innovation at Oracle Construction and Engineering, emphasized the importance of professional collaboration and coordination under current time and quality pressures. He highlighted the value of reliable solutions like CDEs in simplifying workflows and ensuring effective integration with authoring, validation, and complementary tools.

The survey underscores the growing significance of CDEs and BIM workflows in construction organizations over recent years. In the following section, we will introduce Autodesk Construction Cloud, a platform developed by Autodesk, which serves as a CDE offering integrated project management and enhanced collaboration capabilities.

4.8 Level of Development (LOD)

4.8.1 Overview of LOD and Its Role in BIM

In BIM workflows, it is crucial to standardize the **Level of Detail (LOD)** and **Level of Development (LOD)** of objects modeled in a project. Not every component requires the highest level of detail in all stages of a project, as excessive detail can increase time and costs unnecessarily. Regulations such as the **AIA E202-2008** by the American Institute of Architects (AIA) serve as the foundation for LOD definitions. Other countries have developed their own standards, including Italy's **UNI 11337-1:2017** and the United Kingdom's **PAS 1192-2:2013**, which also incorporate the concept of a **BIM Execution Plan (BEP)**. The BEP defines project goals and specifies the appropriate LOD for each part of the model to ensure consistent development throughout the process.

LOD encompasses two aspects:

- **Level of Detail (LOD)**: Refers to the graphical fidelity of an object in the model, focusing on how much the object visually resembles its real-world counterpart.

- **Level of Development (LOD)**: Describes the extent of information associated with the object in the model, including how reliably project team members can use this information for decision-making.

4.8.2 LOD Stages: From LOD 100 to LOD 500

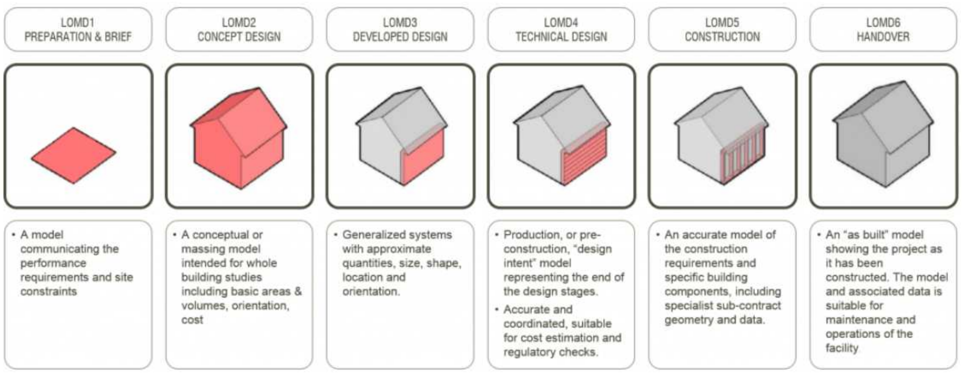


Figure 4.15: LOD description, https://evolve-consultancy.com/lod-lod-loi/

LOD is categorized into six levels, each increasing in graphical and informational detail. These categories balance modeling efficiency and project requirements:

1. **LOD 100**
   Objects are represented symbolically or generically in the model. Information such as cost estimates or material quantities can be derived from other model elements.

2. **LOD 200**
   Objects are represented with approximate geometry, including generic shapes, sizes, locations, and orientations. Non-graphical data may also be included.

3. **LOD 300**
   Objects are modeled with specific and accurate geometry, including precise size, shape, quantity, and orientation. Relevant non-graphical data is attached.

4. **LOD 350**
   This level includes all aspects of LOD 300, along with defined interfaces between building systems. The model accounts for interactions with adjacent elements.

5. **LOD 400**
   The model includes fabrication, assembly, and installation details. This level supports construction activities and is often used for prefabrication.

6. **LOD 500**
   Objects are verified based on as-built conditions, accurately representing the final construction, including size, shape, location, and orientation.

4.8.3 LOD and Its Application in Different Project Phases

Selecting the appropriate LOD for each stage of a project is critical to optimize efficiency and resource allocation. For example:

- **Concept Design**: Lower LODs (e.g., LOD 100-200) suffice for initial massing and layout studies.

- **Design Development**: Intermediate LODs (e.g., LOD 300) provide precise dimensions and configurations for collaboration among disciplines.

- **Construction**: Higher LODs (e.g., LOD 400) are necessary for fabrication and installation.

- **Facility Management**: LOD 500 ensures the model accurately reflects the built environment.

Additionally, Autodesk Revit allows users to manage LOD effectively using its detail view settings (e.g., low, medium, and high), which roughly correspond to LOD 100, 300, and 400.

This flexibility ensures that the appropriate LOD is applied without overloading the model with unnecessary detail.

The LOD consists of 2 elements: The geometry or visual representation of a project – LOG (Level of Geometry); and the data attached to the objects of the BIM model – LOI (Level of Information).

4.9 BIM Dimensions in Use

The BIM project goes beyond the normal 3 dimensional drawing typical of CAD approach, a BIM model suitably used can reach many level of informations such as:

- 2D / 3D: **Typical drawing dimensions**: it can produce 2D/3D drawings, the strength in those dimensions is that the software automatically produces those drawings, directly changing in any view when the operator makes some modification to the model.

- 4D **Time and Construction Sequencing**: The fourth dimension represents time, that's fundamental in manager activity to make a time - plan, to manage all the phases, the build site organization and all activities inside the process, as accessibility and avoid overlaps of different activities that could slow down the entire process.

- 5D **Cost Estimation and Budgeting**: The fifth dimension represents the cost , it permits us to monitor all the resources needed, to make more precisely plans then in the traditional way also thanks to an exact count of materials and the interaction with the fourth dimension to cross timing and costs data.

- 6D **Sustainability and Energy Analysis**: This approach allows us to cross all the data presented in the model, and with interoperability tools to make energy simulation aimed to create different scenarios, to reach the best project choice in terms of sustainability.

- 7D **Facility Management** : Facility Management: Last dimension, applicable to the whole lifecycle of the facility, to make maintenance programs, and to organize all the activities related with the facility usage.

As described by Smith (2014), the BIM dimensions are increasingly, and theoretically infinite:

4D involves linking construction activities, represented in project schedules, with 3D models to create a real-time visual simulation of construction progress over time. Incorporating the dimension of "time" enables an assessment of project buildability and workflow planning. This helps project participants effectively visualize, analyze, and address issues related to the sequence, spatial arrangement, and timing of construction activities. As a result, more accurate schedules and improved site logistics and layout plans can be developed, enhancing overall productivity.

Adding the 5th dimension of "cost" creates a 5D model, which facilitates the automatic generation of cost budgets and detailed financial analyses tied to the project timeline. This integration significantly reduces the time required for quantity take-offs and cost estimations, improves accuracy, decreases disputes caused by ambiguities in CAD data, and allows cost consultants to focus more on optimizing project value.

The 6D model extends BIM functionality to facilities management. The central BIM model, which contains detailed information about building components and engineering systems, serves as a comprehensive database for facilities management. Its ability to include geometry, relationships, and property details makes it a valuable resource for ongoing building operations and maintenance.

Incorporating sustainability features into BIM results in 7D models, which enable designers to meet carbon targets for specific project elements and validate design decisions. Designers can also test and compare different options to optimize sustainability outcomes. In essence, BIM supports designers in predicting project performance before construction begins, adapting more efficiently to design changes, optimizing designs through simulations and analyses, and producing higher-quality construction documentation (Smith, 2014).

Figure 4.16: BIM Dimensions, Eleftheriadis, 2014

4.10 Standards and Guidelines for BIM Adoption

Building Information Modeling (BIM) has become a transformative tool in the architecture, engineering, and construction (AEC) industry, offering clear advantages in efficiency, collaboration, and cost management. To harness its full potential, many countries have developed and adopted specific standards and guidelines to regulate BIM processes, ensure consistency, and facilitate its integration into national and international projects.

4.10.1 International BIM Standards: ISO 19650 and Beyond

The introduction of international BIM standards marks a significant milestone in standardizing BIM processes globally. The **BS EN ISO 19650** series, published in 2018, replaced the earlier **BS 1192** and **PAS 1192** standards used in the United Kingdom. The ISO 19650 series focuses on the organization and management of information during construction projects and throughout the lifecycle of built assets.

This series currently comprises:

- **ISO 19650-1**: Concepts and principles, which establishes a foundational understanding of information management.
- **ISO 19650-2**: Delivery phase of assets, which defines processes during the construction phase.
- **ISO 19650-3**: Operational phase of assets, scheduled for release in 2020, addressing asset management during the building's lifecycle.
- **ISO 19650-5**: Security-minded BIM and smart asset management, which focuses on data protection and digital environments.

These standards aim to reduce fragmentation in BIM practices across countries, creating a unified framework that facilitates interoperability and collaboration on international projects. A critical component of these standards is the focus on **Level of Information Need**, aligning with the growing adoption of BIM maturity levels.

4.10.2 Chinese BIM Standards

China has recognized the transformative potential of BIM and incorporated its principles into national guidelines aligned with international standards like ISO 19650. The country’s **GB/T 51212-2016** “Unified Standard for BIM Application” provides a foundation for BIM implementation in construction projects.

Chinese BIM standards emphasize:

- **Lifecycle Integration**: Mandating BIM for all project phases, from planning and design to operation and maintenance.
- **Interoperability**: Aligning with international standards such as IFC (Industry Foundation Classes) to enable seamless data exchange across platforms.
- **Government-Led Initiatives**: Requiring BIM adoption in large-scale public infrastructure projects, reflecting the government's focus on efficiency and innovation.

These measures ensure that Chinese AEC firms are globally competitive while meeting domestic industry needs. The alignment with ISO 19650 demonstrates China's commitment to harmonizing with international practices while tailoring standards to national contexts.

4.10.3 Employer's Information Requirements (EIR)

The **Employer's Information Requirements (EIR)** is a pivotal document in BIM workflows, providing a structured framework for project requirements. The EIR outlines the employer's expectations for information deliverables, ensuring that all project participants align with the project's goals.

Key components of an EIR include:

1. **Technical Requirements**: Details of BIM software, data formats, and model coordination protocols.
2. **Management Requirements**: Specifications for collaboration, including the use of a **Common Data Environment (CDE)** and coordination workflows.
3. **Commercial Requirements**: Guidelines for contractual arrangements and cost management related to BIM deliverables.

An effective EIR ensures that all stakeholders understand their roles and responsibilities in delivering a successful BIM project.

4.10.4 BIM Execution Plan (BEP)

The **BIM Execution Plan (BEP)** is a project-specific document that defines how BIM will be implemented and managed throughout the lifecycle of a project. It builds upon the EIR and provides a detailed roadmap for achieving project goals.

BEPs are typically divided into two stages:

- **Pre-contract BEP**: Prepared by bidders to demonstrate their understanding of the employer's requirements.
- **Post-contract BEP**: Developed collaboratively by the project team, specifying workflows, roles, responsibilities, and delivery milestones.

The BEP addresses key areas such as:

- **Data Exchange Protocols**: Ensuring compatibility between stakeholders' systems.
- **Model Coordination**: Defining how clashes will be identified and resolved.
- **Quality Assurance**: Establishing processes for model validation and approval.

The BEP acts as a collaborative tool, fostering transparency and accountability among project participants.

4.11 Autodesk Construction Cloud (ACC)

4.11.1 Introduction to Autodesk Construction Cloud (ACC)

Autodesk Construction Cloud is an innovative platform that integrates advanced technology, an extensive builder network, and predictive insights to connect people and data throughout the building lifecycle, from initial design to operations. The platform utilizes **Autodesk Docs** as a unified Common Data Environment (CDE), enabling centralized file management and integrated workflows across projects.

The following offerings are available on the Autodesk Construction Cloud™ platform:

- Autodesk Build
- Autodesk BIM Collaborate
- Autodesk Takeoff
- Autodesk Docs (available both as a standalone offering and included with other tools)
- Autodesk AutoSpecs

All these offerings also include:

- Insight: Provides analytics derived from collected data and includes Construction IQ, an AI-driven tool that helps identify and mitigate project risks. Insights can also be exported for further analysis.

- Administration: Centralized management of users and permissions, along with tools for efficient project setup using templates. Unified authentication across products simplifies access and management.

Autodesk Construction Cloud enables construction teams to seamlessly connect workflows across all project stages, aiming to reduce risk, improve efficiency, and increase profitability.

While Autodesk Construction Cloud encompasses multiple tools and features for various project stages, this thesis focuses primarily on the **Autodesk BIM Collaborate** tool. Given the emphasis on the pre-construction and design phases, Autodesk BIM Collaborate's capabilities and features will be explored in detail to highlight how it supports collaboration, data integration, and efficiency during these critical stages. Other tools within the platform will be briefly introduced to provide broader context.

4.11.2 Features Supporting Collaboration and Data Management

With advanced tools like **BIM Collaborate Pro**, part of the Autodesk Construction Cloud (ACC), design coordination has reached a new level of precision, security, and traceability. A well-structured review process, as emphasized earlier, is essential for achieving significant efficiency gains in project workflows. Establishing this process at both the organizational and project levels is crucial for fostering effective collaboration, as it ensures that all disciplines align with established project standards and procedures from the outset. This structured approach allows diverse teams, each bringing their specialized expertise, to operate cohesively within a unified framework. By doing so, it minimizes the potential for rework, optimizes design iterations, and accelerates the journey toward achieving a finalized design. These advancements underline the transformative impact of design coordination tools like BIM Collaborate Pro in streamlining workflows and enhancing project outcomes. (Source: Autodesk.com, Gabby Winkey, 2024)

With BIM Collaborate Pro, companies can establish a shared coordination space designed explicitly for effective collaboration. This controlled environment allows design data to be securely shared and managed, improving both data security and traceability. Furthermore, the platform's advanced clash detection features empower teams to identify and address potential conflicts early in the design phase, significantly reducing the likelihood of costly errors and delays. By resolving issues proactively, BIM Collaborate Pro ensures a more streamlined and efficient path to successful project completion.

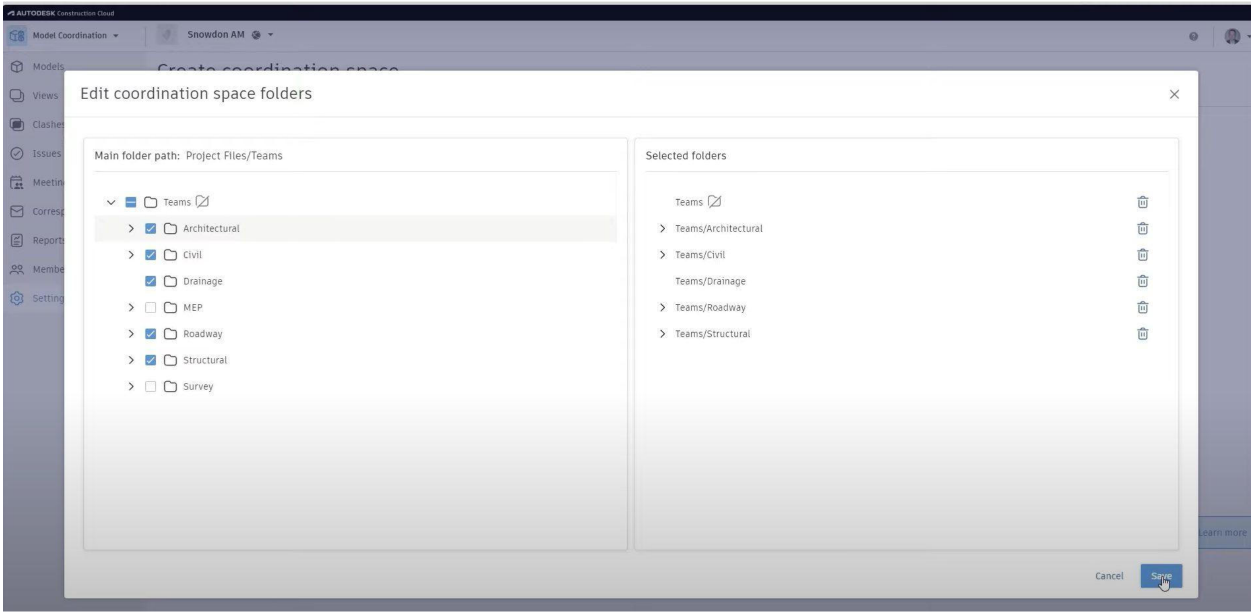


Figure 4.17: Setting up coordination space folders in Autodesk Construction Cloud, Autodesk Website

Within each company, design disciplines require a collaborative framework to refine their designs and enhance quality before sharing with external project stakeholders. BIM Collaborate Pro facilitates this by enabling companies to establish dedicated coordination spaces. In these spaces, teams can conduct internal clash checks and coordinate data across disciplines such as architecture, structural engineering, and MEP. By leveraging live data-sharing connections, internal teams can ensure alignment and consistency across design aspects, creating a solid foundation before integrating them at the broader project level.

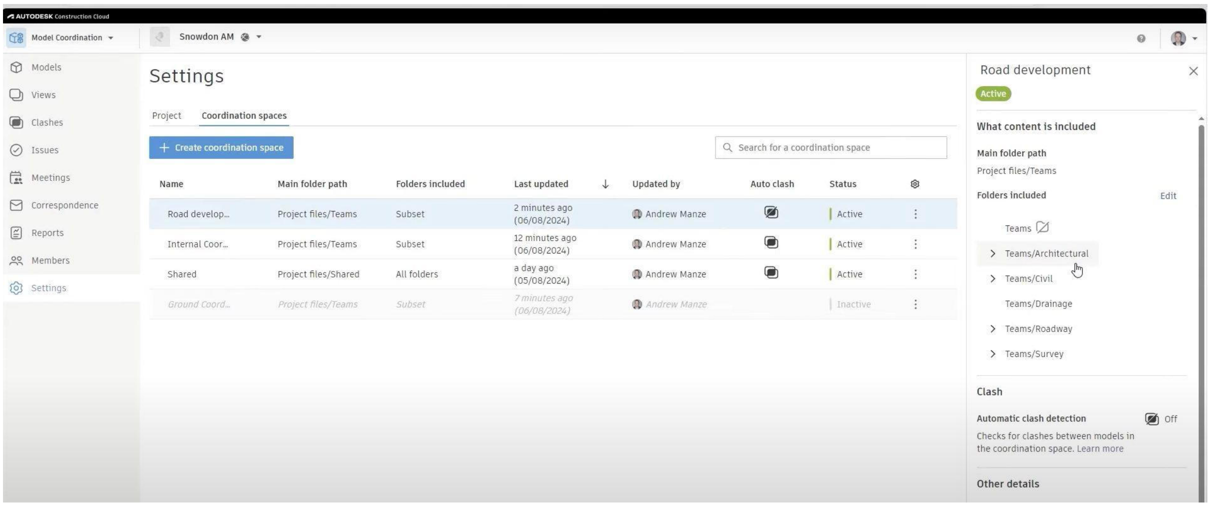


Figure 4.18: Managing coordination spaces in Autodesk Construction Cloud, Autodesk Website

Setting up a project within **Autodesk Construction Cloud (ACC)** typically begins with project templates. These templates house essential parameters, standards, and member permissions, ensuring consistency and efficiency across multiple projects. Folder-level permissions enable project administrators to regulate access based on team roles, restricting collaborators to the data relevant to their responsibilities. This security-focused methodology is vital for safeguarding sensitive project information while maintaining streamlined workflows.

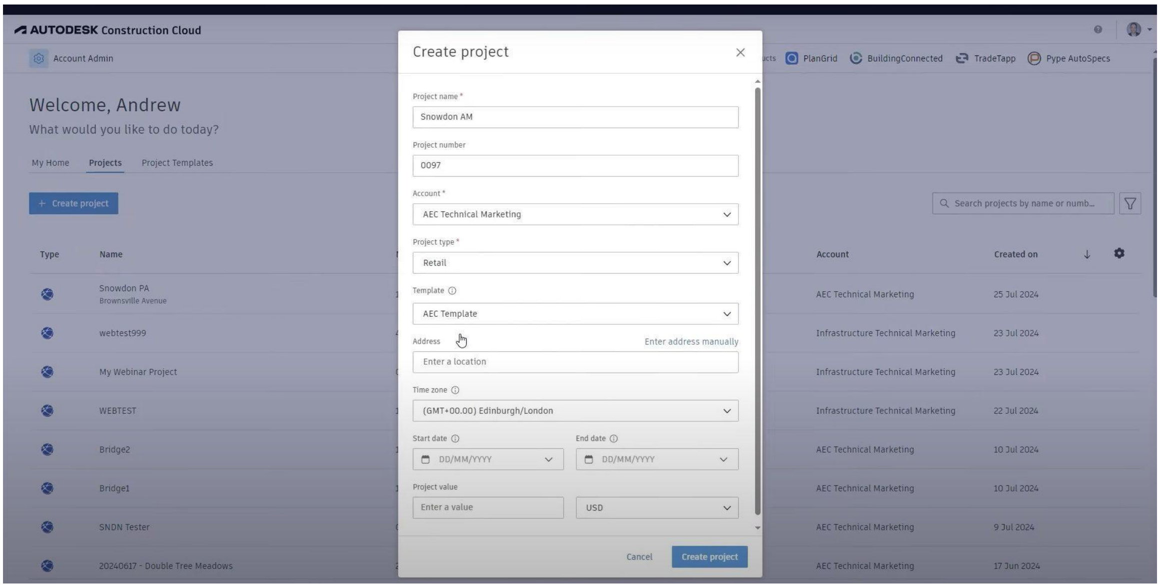


Figure 4.19: Creating a project template in Autodesk Construction Cloud, Autodesk Website

The refined standard project management folder structure and templates in Autodesk Construction Cloud (ACC) encourage participants to utilize all available modules, minimizing reliance on email and spreadsheets for project management.

As construction projects evolve, BIM Collaborate Pro coordination spaces are designed to adapt seamlessly. Teams can modify coordination spaces by adding new ones, adjusting content folders, enabling clash detection, or renaming spaces to align with changing project needs. This flexibility ensures that the coordination setup stays relevant and effective throughout the project lifecycle.

ACC simplifies data sharing across teams. For example, when a structural design team creates a data package, it is shared along a project timeline. Other teams, such as the MEP team, can review this data within the shared environment. If the MEP team identifies the structural data as relevant, they "consume" it, integrating it into their workflows to inform their design decisions. This collaborative process improves coordination while maintaining a record of interactions for traceability and reliability.

Effective issue tracking is essential in collaborative projects. If a clash or design concern arises, it is logged and managed directly within ACC. For instance, a detected clash between structural and MEP elements results in an issue being raised and assigned to the appropriate team. Templates pre-populate responsible members and response timelines, ensuring structured follow-ups. Team members can address these issues, revise designs as necessary, and share updated models, keeping all stakeholders aligned throughout the resolution process.

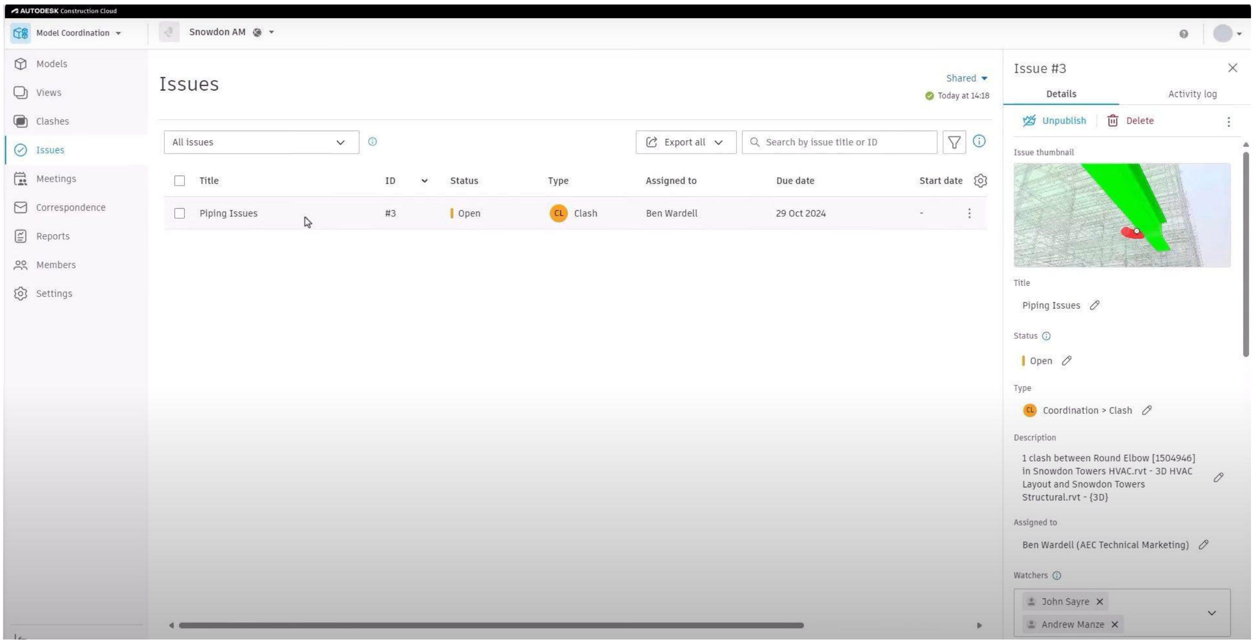


Figure 4.20: [Manage issues in Autodesk Construction Cloud](), Autodesk Website

4.12 Revit Teamwork & Collaboration

4.12.1 Introduction

Collaboration has become an essential aspect of modern architectural, engineering, and construction (AEC) projects, particularly as project complexities continue to grow. Effective teamwork ensures that designs integrate seamlessly across disciplines while minimizing costly delays and rework. At the heart of collaborative processes lies **Building Information Modeling (BIM)**, a methodology that facilitates data-driven design and coordination. Autodesk Revit, one of the leading BIM tools, has transformed how professionals collaborate by providing a platform for **real-time, centralized teamwork**.

Unlike traditional CAD-based workflows, which often rely on fragmented, discipline-specific drawings, Revit enables all project stakeholders to contribute to a **single shared model**. This shared environment allows for a more integrated approach, breaking down silos between architects, engineers, and contractors. Collaboration in Revit is supported by tools like **worksharing, cloud-based platforms (e.g., Autodesk Construction Cloud), and real-time synchronization**, all of which streamline communication, improve decision-making, and reduce errors.

Revit's collaboration features are particularly valuable in large-scale projects where multiple team members, sometimes across geographic locations, must work together. By providing features such as **worksets, automatic change tracking, and conflict resolution tools**, Revit ensures that teams can coordinate effectively without duplicating efforts or overwriting critical work. Furthermore, its integration with cloud platforms enables seamless file sharing, version control, and accessibility, further enhancing productivity.

The implementation of these collaboration steps and methodologies has been explored through our **Workflow Simulation Using Revit's Collaborate Tab**, which is discussed in Chapter 5. There, we apply these principles in a controlled environment, testing Revit's worksharing features, clash detection, and real-time model synchronization. The simulation provides a hands-on evaluation of how Revit supports interdisciplinary collaboration and addresses common coordination challenges in AEC projects.

4.12.2 Common Data Environment (CDE) for Data Sharing

A **Common Data Environment (CDE)** is a centralized repository used to store, manage, and share all project-related information. It ensures that stakeholders in an Architectural, Engineering, and Construction (AEC) project access a “single source of truth”. This approach reduces miscommunication and inconsistencies while ensuring consistency, transparency, and compliance with industry standards like ISO 19650.

CDEs can be implemented using:

1. **Local Network Drives**: On-premise systems where files are stored on shared servers accessible via a company network.
2. **Cloud-Based Platforms**: Internet-hosted platforms like Autodesk Construction Cloud (ACC) that allow remote access and advanced collaboration features.

Key Advantages of a CDE

1. **Data Consistency**: CDE ensures that every team member and all stakeholders access the latest, most accurate information.
2. **Transparency**: Facilitates open communication by tracking updates and contributions from all collaborators.
3. **Scalability**: Supports small-scale projects to enterprise-level, multi-disciplinary collaborations.
4. **Compliance**: Meets industry standards such as ISO 19650, which defines processes for managing BIM information.

Comparing CDE Implementations

Feature	Local Network Drive	Cloud-Based Platform
Accessibility	Limited to Physical Location	Remote Access Globally
Collaboration Features	Manual Version Control	Built-in Tools like Clash Detection

Cost	Lower Upfront Costs	Subscription-based
Performance	IT-dependent	Requires Internet Connectivity

Table 4.1: CDE Implementations, Elaborated by Authors

Integration with Revit Workflow

- **Using Network Drives**: Central models are stored on shared drives; team members synchronize changes directly to the central model.
- **Using Cloud Platforms**: Central models are hosted on cloud services, enabling advanced features like automatic synchronization, clash detection, and issue tracking. Ideal for projects involving distributed teams.

Chapter 5 (Simulation)[1]

5. BIM vs. CAD

A Practical Analysis of Collaboration and Workflow Efficiency

5.1 Introduction and Objectives

As mentioned earlier in chapter 1, the AEC industry has faced persistent challenges in streamlining collaboration across various disciplines and stakeholders. The integration of BIM has often been proposed as a solution to address these inefficiencies, yet the practical implications of adopting BIM compared to traditional CAD workflows require further exploration. This chapter focuses on two distinct simulations aimed at evaluating collaboration and comparing BIM-based and CAD-based workflows in a controlled setting.

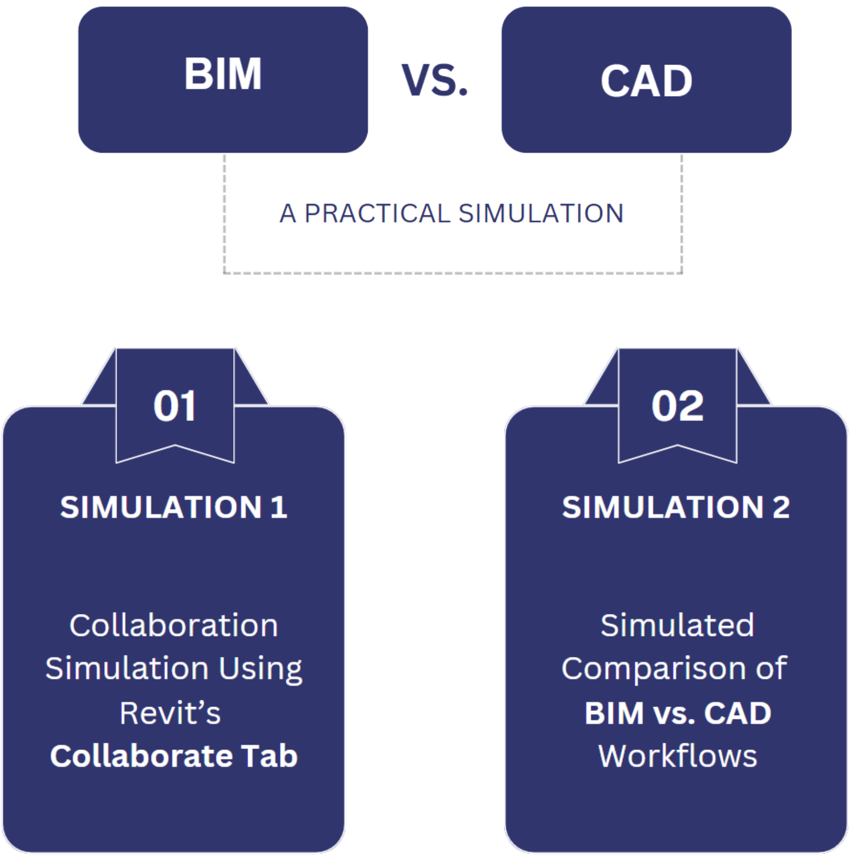


Figure 5.1: Collaboration and Workflow Simulation Description, Elaborated by Authors

[1] The simulations presented in this chapter are based on a single project—the extension of Yuan Ding Middle School. While this case study provides valuable insights into the practical differences between BIM and CAD workflows, it is important to acknowledge that the findings may not be fully generalizable to all AEC projects. The results are influenced by the specific characteristics of the project, such as its scale, complexity, and the disciplines involved.

The two simulations conducted in this study are:

1. **Collaboration Simulation Using Revit's Collaborate Tab:** This simulation analyzes the use of Revit's collaboration tools to facilitate real-time interdisciplinary teamwork in a shared project environment.

2. **Simulated Comparison of BIM vs. CAD Workflows:** This simulation directly compares the efficiency of BIM (Revit) and CAD (AutoCAD & SketchUp) workflows by tracking time, accuracy, and coordination effectiveness during design revisions.

The primary objective of these simulations is to analyze how BIM and CAD facilitate or hinder collaboration when applied to a shared architectural project. Specifically, this study recreates a collaborative scenario where two disciplines—architecture and mechanical engineering—work together on designing an extension for Yuan Ding Middle School. The exercise is designed to mimic real-world project conditions, providing insights into the practical implications of both workflows for interdisciplinary collaboration.

These simulations align closely with the overarching goals of this thesis, which seeks to identify and address collaboration challenges in the AEC industry. It contributes to a deeper understanding of the practical limitations of traditional CAD workflows while showcasing the innovations and efficiencies that BIM workflows can bring. By systematically comparing the two approaches, the study aims to offer concrete evidence for the benefits and challenges associated with each method.

5.1.2 Relevance to Thesis Focus

These simulations are particularly valuable because they connect theoretical insights about collaboration with real-world observations drawn from a practical case. Collaboration in the AEC industry often involves complex exchanges of information, iterative design changes, and coordination across various disciplines. This study explores these dynamics in the context of two distinct workflows:

Traditional CAD Workflow: Widely used for decades, CAD is characterized by its reliance on disconnected tools for 2D drafting (e.g., AutoCAD) and 3D modeling (e.g., SketchUp). While CAD offers simplicity and familiarity, it often falls short in enabling seamless updates, real-time collaboration, and integration of multidimensional project data.

BIM Workflow: In contrast, BIM provides an integrated platform where 3D models, data, and disciplines converge. Tools such as Revit allow for real-time collaboration, parameter-driven designs, and automated updates across views, schedules, and documentation. BIM's collaborative potential, however, needs to be tested for its efficiency in managing complex interdisciplinary projects.

The simulation aims to evaluate several key parameters:

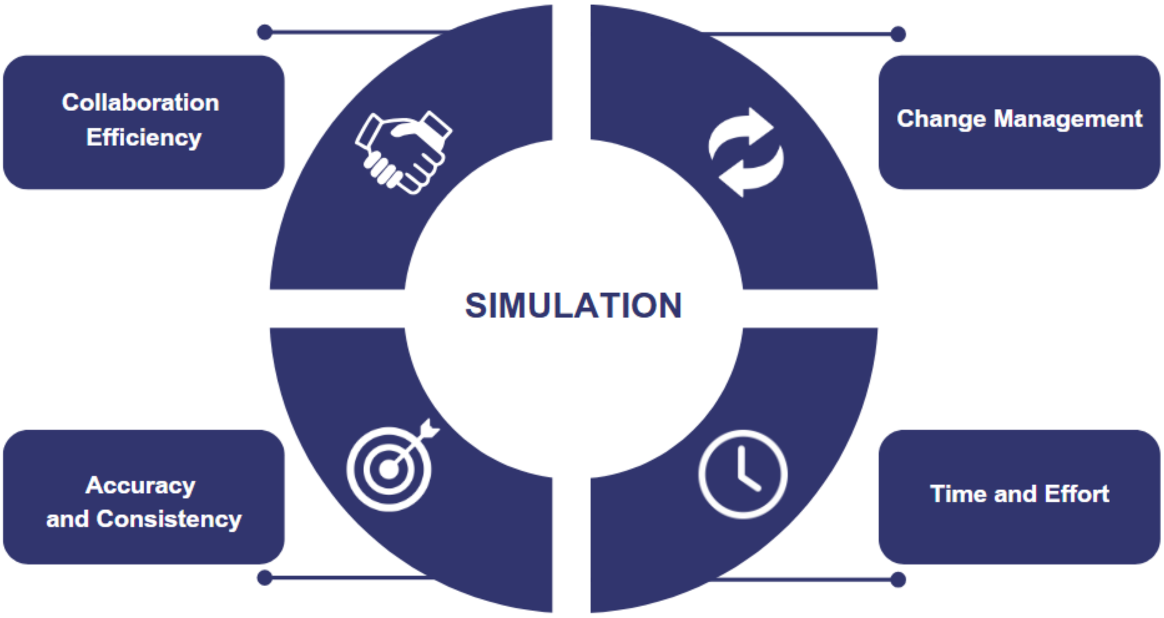


Figure 5.2: Key Parameters of the Simulation, Elaborated by Authors

Collaboration Efficiency: How well do the two workflows facilitate communication and coordination between team members?

Change Management: How efficiently can each workflow adapt to iterative changes in design and requirements?

Accuracy and Consistency: How effectively do the workflows ensure the consistency and accuracy of project documentation?

Time and Effort: What are the relative time and labor investments required for completing similar tasks using each workflow?

By analyzing these parameters, these simulations provided critical insights into the advantages and limitations of each system. The results of these simulations directly align with the thesis's broader goals of improving collaborative practices within the AEC industry. By exploring how BIM addresses the inefficiencies of traditional workflows, the simulations build a compelling case for adopting BIM as a transformative tool in interdisciplinary collaboration.

5.2 Workflow Simulation Using Revit’s Collaborate Tab

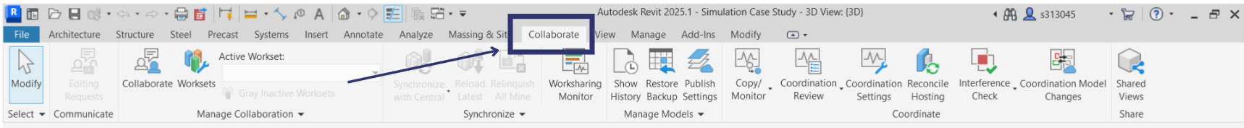


Figure 5.3: Collaborate Tab in Revit Software, Elaborated by Authors

This simulation was designed to reflect real-world interdisciplinary collaboration using Revit. The authors acted as Architects and Engineers working on a single model, applying Revit’s collaboration features such as the "Collaborate" tab, worksets, synchronization, and worksharing display. This approach simulated the complex interdisciplinary collaboration often required in real-world AEC projects.

5.2.1 Process

To enhance the understanding of collaborative workflows in Revit, several critical processes were integrated into this simulation:

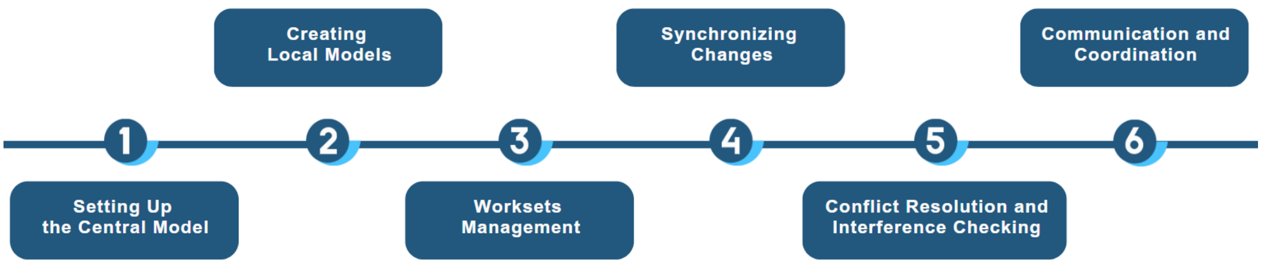


Figure 5.4: Simulation N.1 Process, Elaborated by Authors

1. Setting Up the Central Model

The **central model** serves as the foundation for collaboration in Revit. In a **Common Data Environment (CDE)** setup, this model is stored in a shared location—such as a network drive or a cloud-based platform—ensuring that all collaborators access the same, up-to-date version in real time. This centralized approach to **BIM collaboration** facilitates coordination across disciplines and significantly enhances **data consistency**.

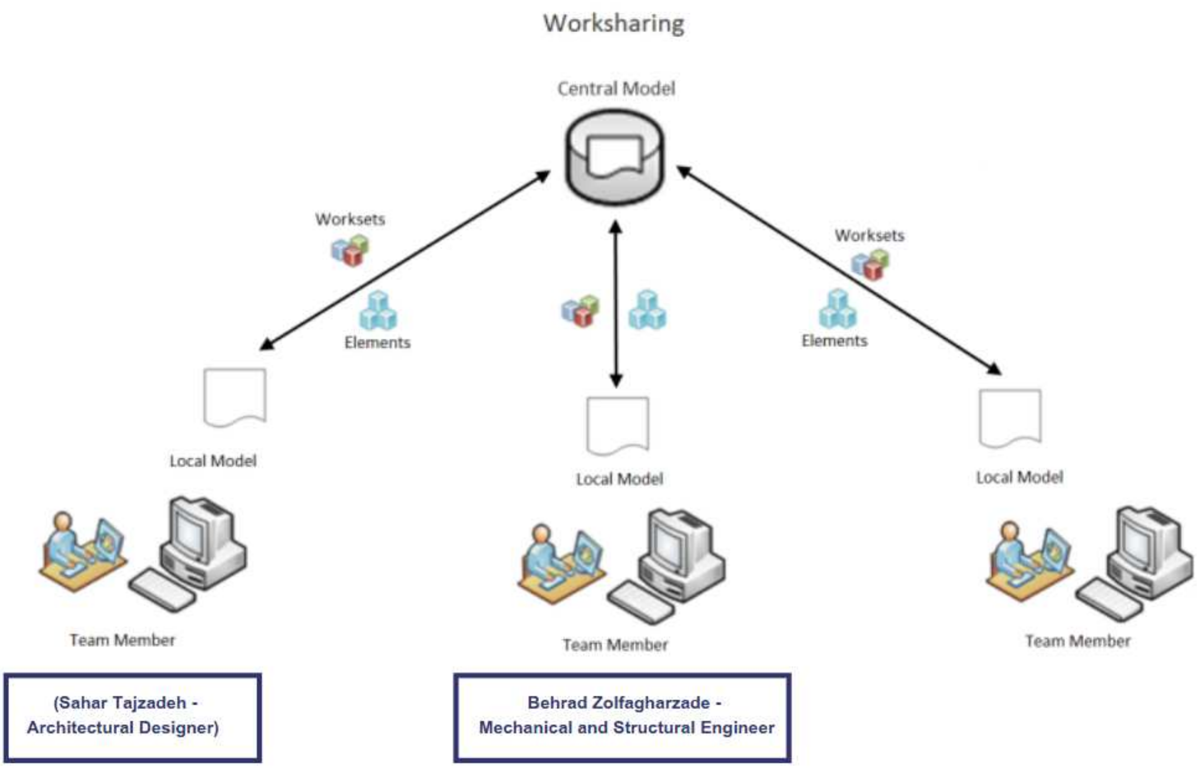


Figure 5.5: Revit Worksharing Diagram, Autodesk website

https://www.autodesk.com/support/technical/article/caas/tsarticles/ts/EWuUSeReChSgcVOATGdV4.html

In real-world projects, setting up the **central model** is typically the responsibility of a **BIM Manager or Coordinator**, as they have the technical expertise to configure worksharing settings correctly and ensure that the model adheres to **project guidelines**. Proper setup is crucial because it helps:

- **Minimize errors** by maintaining a single source of truth for all stakeholders.
- **Prevent workflow disruptions** by structuring model permissions and responsibilities.
- **Enhance coordination** across disciplines like architecture, structure, and MEP.

Since this was a simulation with only the authors as participants, we (the authors) took on the role of the BIM Manager ourselves, dividing the responsibilities and setting up the central model independently.

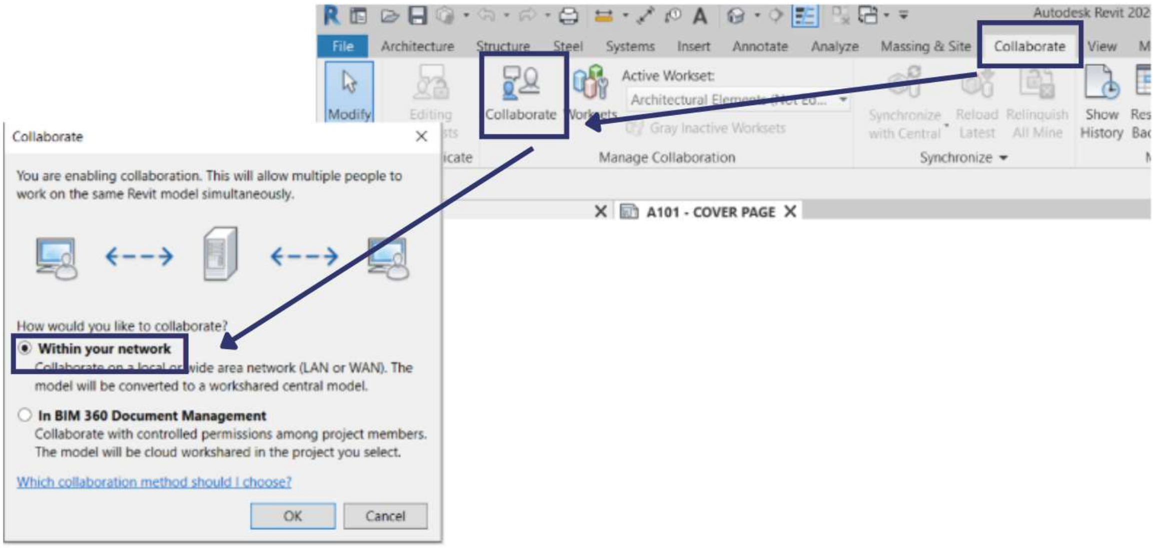


Figure 5.6: Setting Up the Central Model, Elaborated by Authors

2. Creating Local Models

Local models are individual copies of the central model that team members use to make changes without directly editing the shared file. The central model is accessed from the shared repository, and the local files are synchronized regularly to incorporate updates from other team members. This ensures data consistency while allowing team members to work independently. Once the central model was set up, we proceeded with **creating local models**, ensuring that each team member worked independently while synchronizing updates periodically.

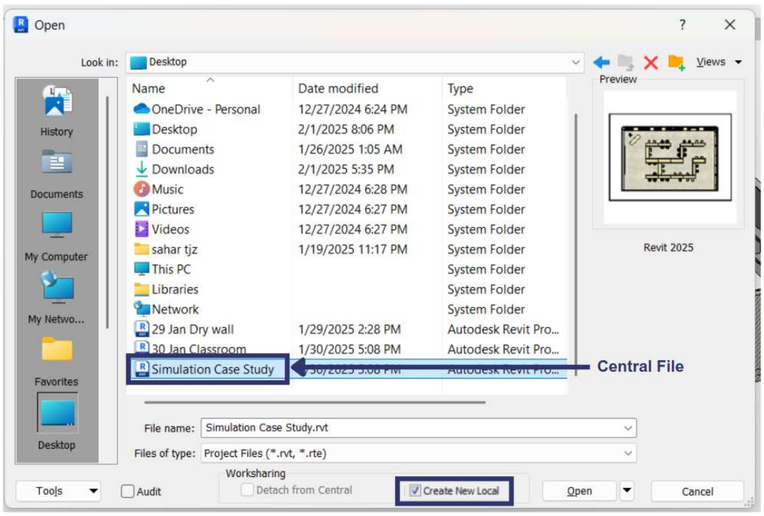


Figure 5.7: Creating Local Models, Elaborated by Authors

3. Worksets Management:

To enable parallel work, we **divided** the project into **separate worksets**, assigning each of us to different responsibilities.

Worksets Created:

- **Architectural Workset:** Included the building's overall structure, layout, and design.
- **Mechanical Workset:** Focused on the HVAC systems, including ducts, diffusers, and mechanical equipment.
- **Structural Workset:** Included the primary structural components of the building, such as columns, beams, load-bearing walls, foundations, and structural framing.

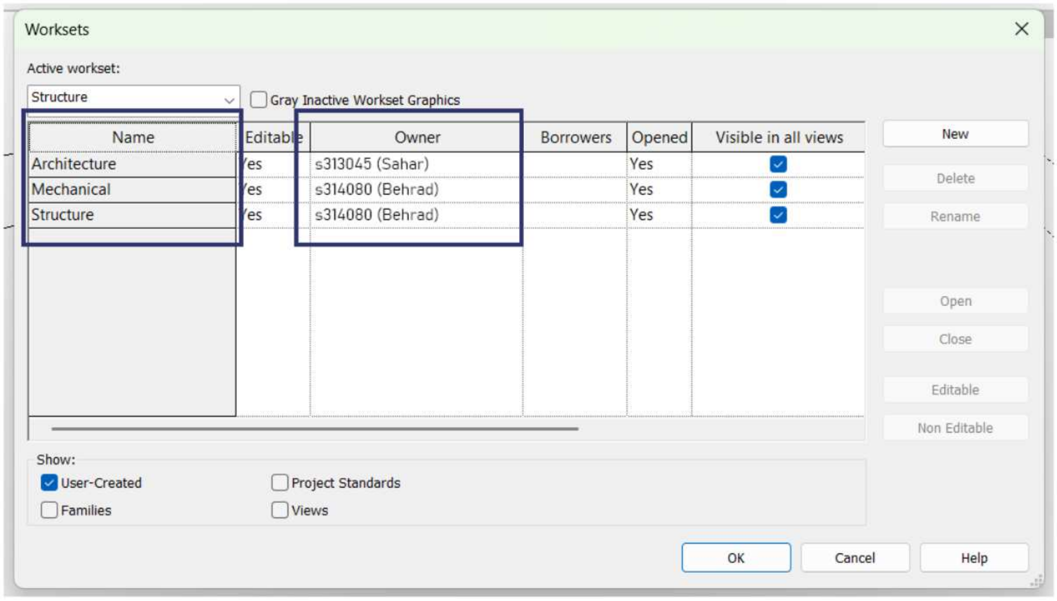


Figure 5.8: Creating multiple worksets, Elaborated by Authors

Each author was assigned specific tasks and used Revit's features to collaborate effectively.

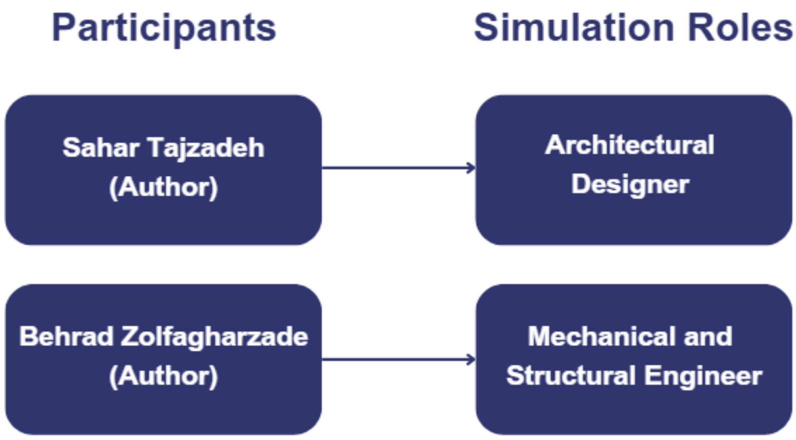


Figure 5.9: Assigned roles in the simulation N.1, Elaborated by Authors

4. Synchronizing Changes

Synchronization is the process of updating the central model with changes made in a local model while simultaneously retrieving updates made by other collaborators. This two-way exchange ensures that all team members are working with the most current version of the model while maintaining their contributions.

Throughout the simulation, we **synchronized** our local models with the **central model**, updating changes while retrieving updates from each other.

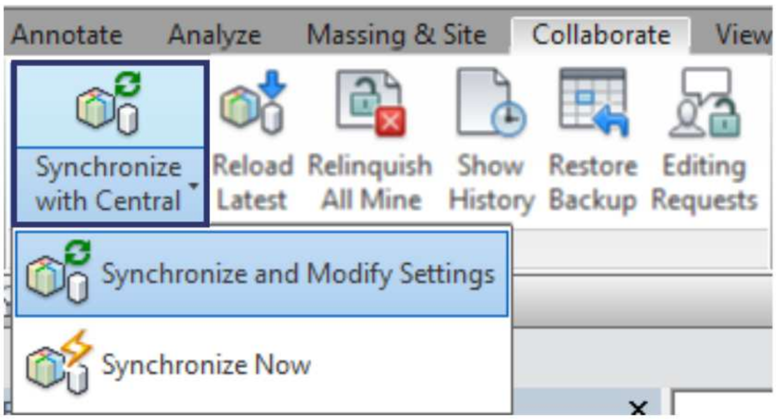


Figure 5.10: Synchronizing Changes in Revit Collaborate Tab, Elaborated by Authors

5. Clash Detection, Conflict Resolution and Interference Checking

Clashes and conflicts occur when different elements of a **Building Information Model (BIM)** interfere with each other, causing design inconsistencies or constructability issues. These problems typically arise when multiple disciplines (Architecture, Structural, and MEP) work together in a shared Revit model.

As part of the **simulation**, we tested how Revit **manages conflicts** when they happen.

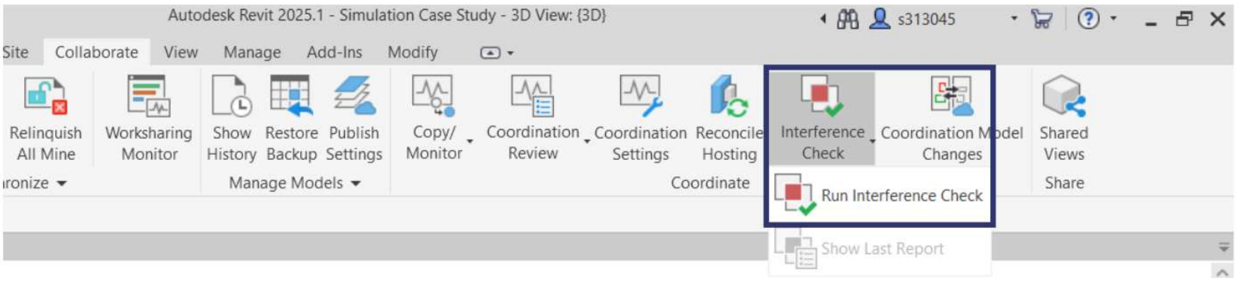


Figure 5.11: Interference Checking in Revit Collaborate Tab, Elaborated by Authors

We decided to run the clash detection between columns and walls to identify any potential conflicts within our model. After executing the clash detection process, we received a detailed report highlighting the detected clashes. This allowed us to analyze the points of conflict and assess how effectively Revit's clash detection tools could facilitate early issue resolution in a collaborative workflow.

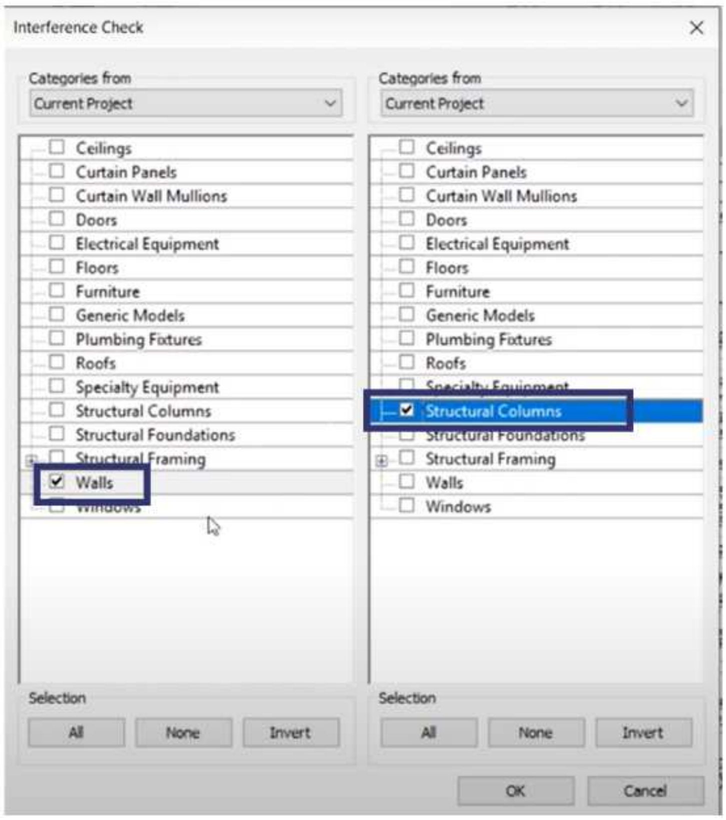


Figure 5.12: Choosing categories for clash detection, Elaborated by Authors

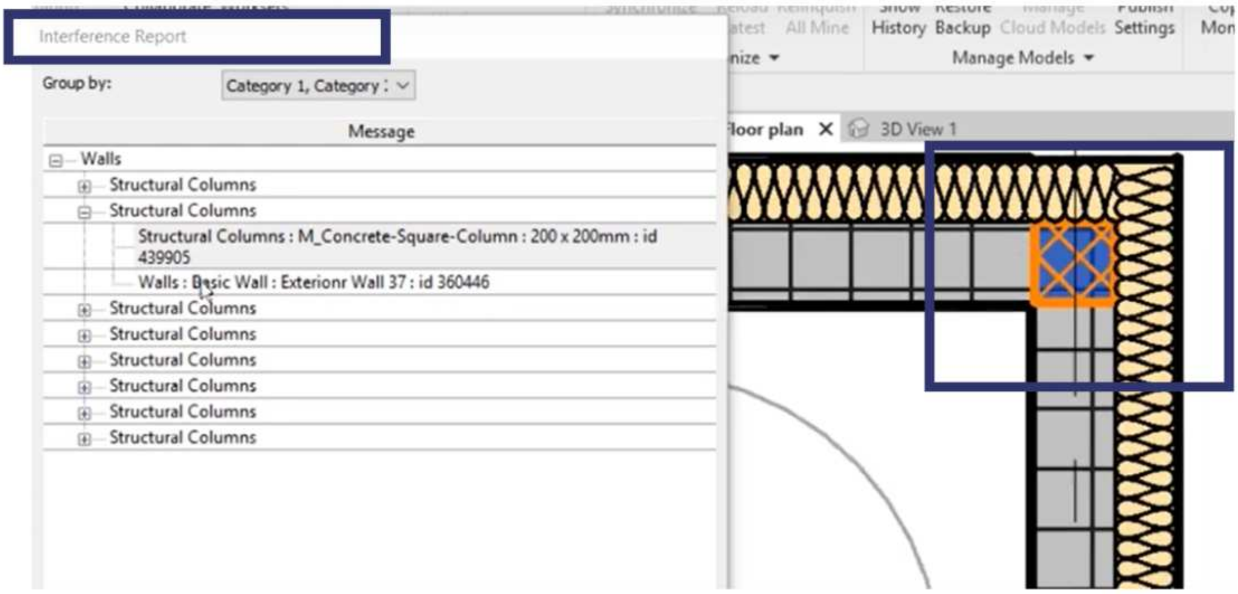


Figure 5.13: Result of clash detection, Conflict of structural column and wall, Elaborated by Authors

5.2.2 Communication and Coordination

To resolve the clashes, we first identified the specific elements causing conflicts and determined our respective responsibilities—**walls were managed by Sahar (architect), while structural columns were managed by Behrad (structural engineer).** Using Revit's collaboration tools, we discussed possible solutions. Sahar could either adjust the wall placement to accommodate the columns, or if a column needed modification, she could send a request to Behrad for access. Alternatively, Sahar could simply notify Behrad about the clash, allowing him to make the necessary structural adjustments. Once we implemented the changes, we resynchronized our local models with the central model and reran the clash detection to confirm that all issues were resolved.

5.2.3 Conclusion

The **Workflow Simulation Using Revit's Collaborate Tab** provided a hands-on demonstration of how Revit's collaborative features facilitate interdisciplinary teamwork in a BIM environment. By taking on multiple roles within the simulation, we experienced firsthand how setting up a **central model**, managing **worksets**, and synchronizing **local models** contribute to efficient collaboration. The clash detection and conflict resolution process highlighted Revit's ability to identify and mitigate design inconsistencies before they escalate into construction issues. Additionally, using **communication tools** within Revit allowed us to manage responsibilities effectively, demonstrating how architects and engineers can collaborate seamlessly on a shared model. This simulation reinforced the value of **BIM-enabled workflows** in enhancing coordination, minimizing errors, and streamlining project execution, further supporting the thesis's objective of improving collaboration in the AEC industry.

While the **collaborative workflow in Revit** allowed for real-time coordination, structured **worksharing**, and efficient **clash detection**, attempting to achieve the same level of integration using a **traditional CAD workflow** would introduce significant challenges. In a CAD-based environment, collaboration would typically rely on **manually exchanging files** between disciplines, often through email or shared drives, leading to **version control issues** and outdated information. Instead of **synchronized models**, architects and engineers would need to manage **separate 2D drawings and 3D models**, requiring manual updates for every design change. Clash detection would be far more difficult, relying on overlaying different discipline drawings (e.g., structural vs. architectural plans) rather than using an automated clash detection tool. Resolving conflicts would be a slower, more error-prone process, requiring back-and-forth communication rather than immediate in-software coordination. Additionally, CAD lacks **live collaboration tools**, meaning that each user would need to **wait for updated files** rather than working on a **shared model**. As a result, a CAD-based workflow would likely lead to **delays, miscommunications, and increased rework**, reinforcing the advantages of BIM for interdisciplinary collaboration.

5.3 Simulated Comparison: BIM vs. CAD

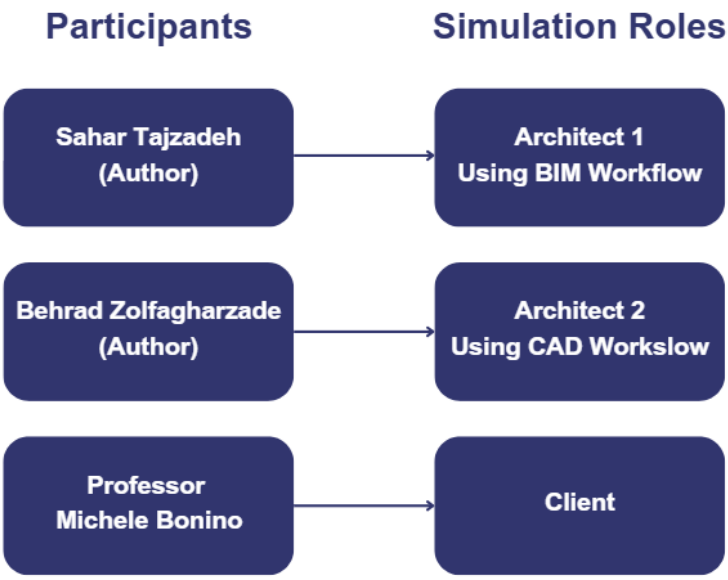


Figure 5.14: Assigned roles of simulation N.2, Elaborated by Authors

To illustrate the practical differences between BIM and traditional CAD workflows, a simulated project workflow was conducted where we -the authors- acted as designers, and our professor assumed the role of the client. The scenario simulated typical revisions and updates on a project, comparing the time and effort required to implement changes using BIM (Revit) versus CAD tools (AutoCAD for 2D documentation and SketchUp for 3D modeling).

5.3.1 Clarifying Roles and Responsibilities

In the BIM vs. CAD simulation, the roles and tool assignments were carefully structured to reflect real-world scenarios and ensure a fair comparison between the two workflows.

The simulation was designed around weekly revision sessions, during which the architects received feedback from the "client" and implemented changes across plans, sections, elevations, and 3D models. To maintain consistency with the logic of the thesis and align with our professional experiences, we assigned specific tools to each author for the purpose of this chapter.

5.3.2 Tool Assignments and Rationale

Sahar utilized Revit, leveraging its integrated BIM capabilities to update the 3D model, plans, sections, and elevations simultaneously. This choice reflects Sahar’s proficiency with BIM tools and experience in using Revit for collaborative projects.

Behrad employed SketchUp for 3D modeling and AutoCAD for 2D documentation, updating plans, sections, and elevations separately. This approach mirrors Behrad's familiarity with traditional CAD workflows and expertise in using SketchUp and AutoCAD for design tasks.

The decision to present this specific simulation (where Sahar used BIM tools and Behrad used CAD tools) was intentional. It aligns with the roles we assumed during our internships, ensuring consistency with the practical experiences that informed this thesis. Additionally, by alternating roles in other simulation studies—where Behrad worked with BIM tools and Sahar with CAD tools—we were able to cross-validate the findings and minimize potential biases.

5.3.3 Equal Proficiency in Tools

Throughout multiple simulation studies, we observed that both authors had comparable proficiency in their respective tools. This ensured that the comparison between BIM and CAD workflows was not skewed by differences in skill levels. By maintaining this balance, the simulation results accurately reflect the inherent efficiencies and challenges of each workflow, rather than being influenced by individual expertise.

Tasks and revisions were meticulously documented in detailed tables, noting the time taken for each step and the associated processes. This approach allowed for a direct comparison of workflows and highlighted the advantages and limitations of each methodology.

5.3.4 A Detailed Week: Major Revisions

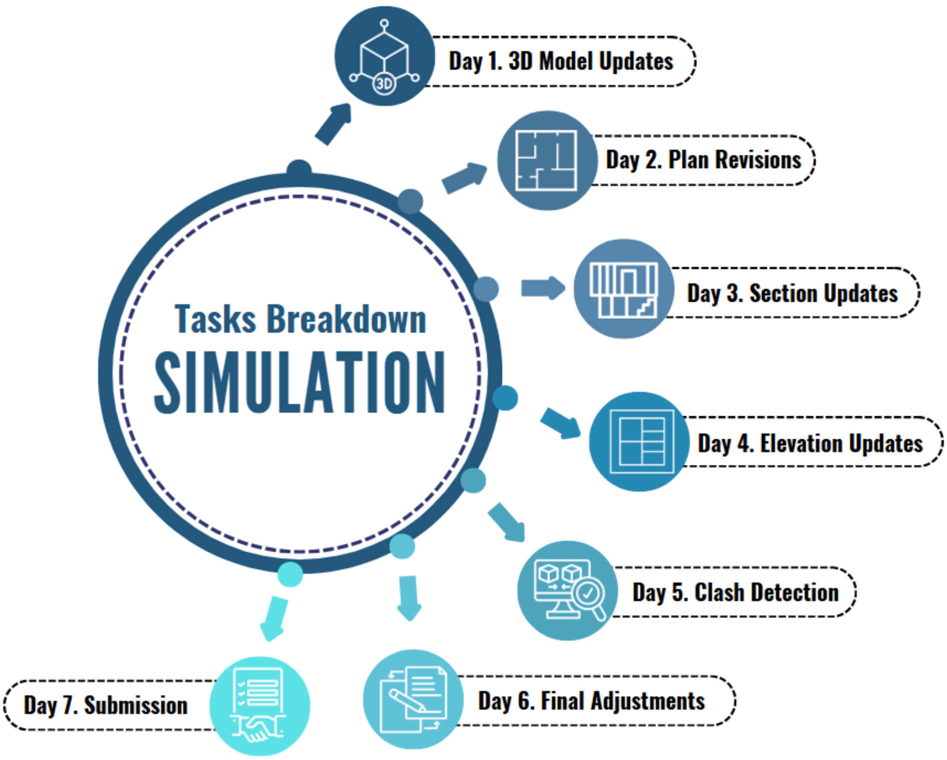


Figure 5.15: Simulation Daily Task Breakdown, Elaborated by Authors

Below, we detail one particular week in the simulation that demonstrated significant differences between the two workflows. During this week, a substantial revision was introduced by the "client," requiring modifications to the 3D model that cascaded into all associated documents (plans, sections, and elevations).

Sahar (BIM Approach with Revit):

- Updated the 3D model directly in Revit.
- Leveraged Revit's parametric capabilities to automatically apply changes across all related documents (plans, sections, and elevations).
- Simultaneous updates reduced redundancy and saved significant time.

Behrad (CAD Approach with SketchUp and AutoCAD):

- First updated the 3D model in SketchUp.
- Manually transferred changes to plans in AutoCAD, requiring redrawing or adjusting elements.
- Redrew sections and elevations from scratch to reflect the new 3D model changes.

5.3.4.1 Tasks to Be Completed by the End of the Week

The following tasks were identified as necessary to complete the revision:

Task	Sahar (BIM - Revit)	Behrad (CAD - SketchUp & AutoCAD)
Modify 3D model	Completed in Revit. changes auto-updated in associated views.	Updated in SketchUp. Nothing is auto-updated.
Update plans	Auto-updated with 3D model.	Updated (redrawn) manually in AutoCAD.
Update sections	Auto-updated with 3D model.	Redrawn manually in AutoCAD.
Update elevations	Auto-updated with 3D model.	Redrawn manually in AutoCAD.

Table 5.1: Tasks to Be Completed by the End of the Week, Elaborated by Authors

This simulation highlighted the inherent efficiencies of BIM's integrated workflows compared to the more labor-intensive nature of CAD-based processes. Behrad’s use of Revit allowed for streamlined, automatic updates across the board, while Sahar faced the challenges of manually coordinating changes between tools and drawing types.

Below, we present the week's tasks and progress in a day-by-day breakdown, showcasing the work done by Behrad (CAD) and Sahar (BIM).

Day	Task	Behrad (CAD)	Time Spent	Sahar (BIM)	Time Spent	Time Saved Using BIM (%)
Day 1	3D Model Updates	Began modifying the 3D model in SketchUp.	6 hours	Updated the 3D model in Revit, automatically updating all related documents.	3 hours	50%
Day 2	Plan Revisions	Exported 3D views from SketchUp for reference and started manually redrawing plans in AutoCAD.	8 hours	After updating the 3d model, all the plans were automatically updated. A few adjustments done manually.	2 hours	75%
Day 3	Section Updates	Redrawing sections manually in AutoCAD.	4 hours	Adjusting auto-generated sections in Revit.	2 hours	50%
Day 4	Elevation Updates	Creating elevations manually in AutoCAD based on the revised 3D model from SketchUp.	4 hours	Reviewing and adjusting elevations that were already auto-generated in Revit.	1 hour	75%
Day 5	Clash Detection	Manual checking between AutoCAD and SketchUp.	5 hours	Using clash detection tools (Navisworks) to ensure consistency across disciplines.	2 hours	60%
Day 6	Final Adjustments	Adjusting all the documents again after detecting conflicts and clashes.	8 hours	Applied changes after clash detection and adjusting documents to finalize.	3 hours	63%
Day 7	Submission	**Incomplete work** – Not all documents finished.	Total: 35 hours	**100% completed on time** – Submitted the full set of updated documents on time with no missing elements.	Total: 13 hours	-

Table 5.2: Day-by-day tasks breakdown and the results, Elaborated by Authors

5.3.4.2 Process Breakdown (Day 1 - Day 7)

This section details our workflow simulation, comparing the time spent and efficiency of BIM (Revit) vs. CAD (AutoCAD & SketchUp). Each day, we worked through specific tasks, documenting the process and identifying key differences in execution.

Day 1: 3D Model Updates

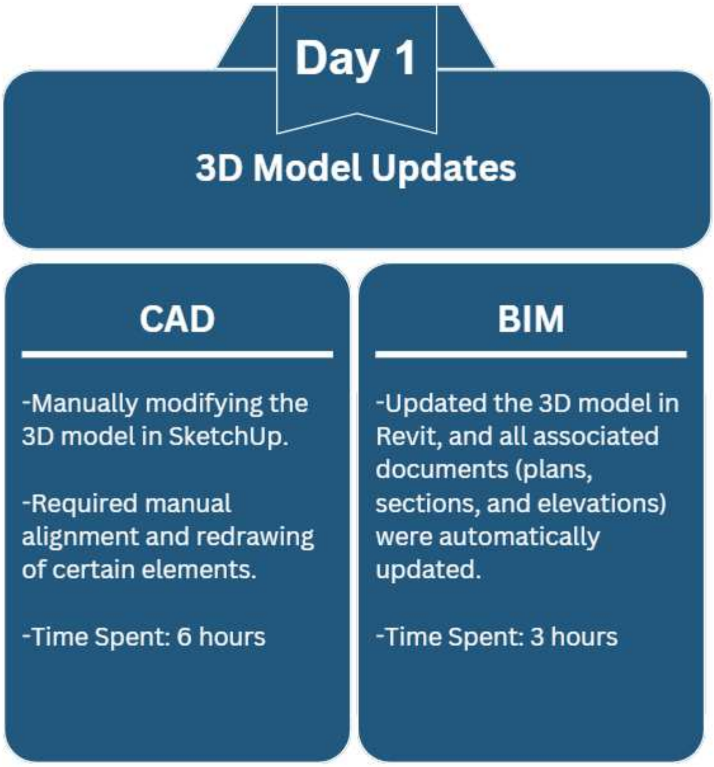


Figure 5.16: Day 1 summary, Elaborated by Authors

The first step of our simulation was to edit and update the 3D model based on the requested changes.

Behrad (CAD) started modifying the model in SketchUp, manually adjusting structural and spatial elements. Each adjustment required individual edits without direct integration with the 2D drawings. (Time Spent: 6 hours)

Sahar (BIM), using Revit, made the same modifications in a parametric environment, where all updates in the 3D model automatically reflected in the related plans, sections, and elevations. (Time Spent: 3 hours)

Since Revit allows linked updates between the 3D model and 2D documentation, Sahar's process was significantly faster. In contrast, Behrad had to manually check and adjust multiple views to ensure consistency, making the CAD process more time-consuming.

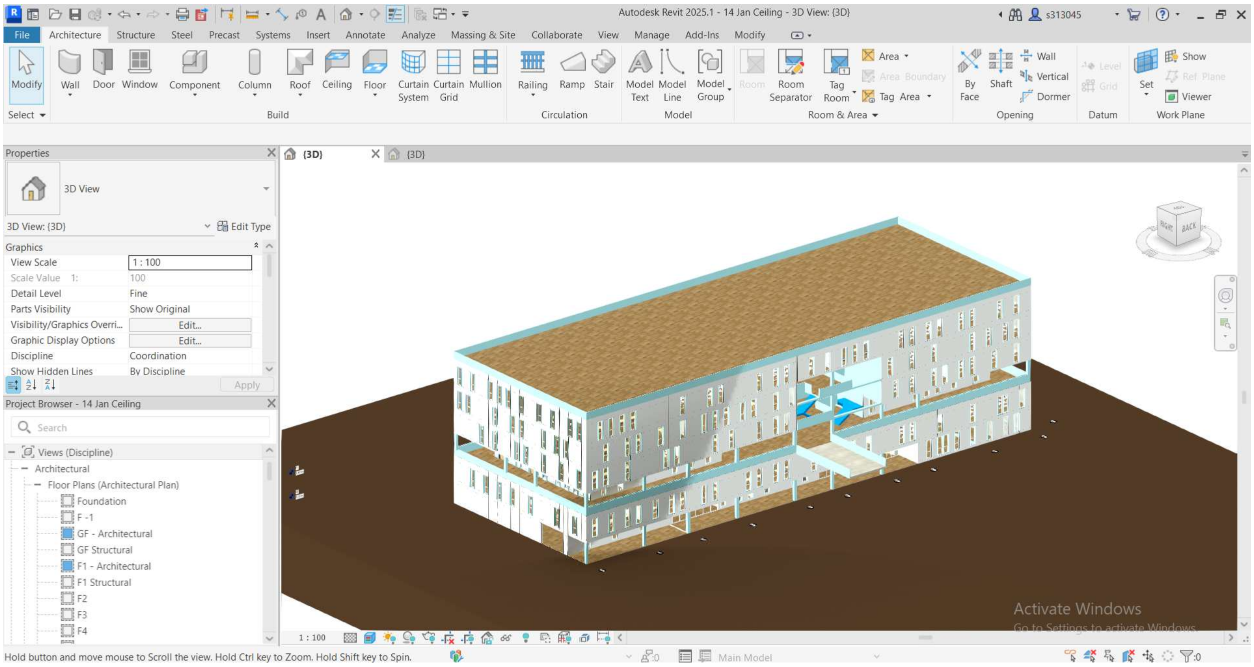


Figure 5.17: 3D Model in Revit before editing, Elaborated by Authors

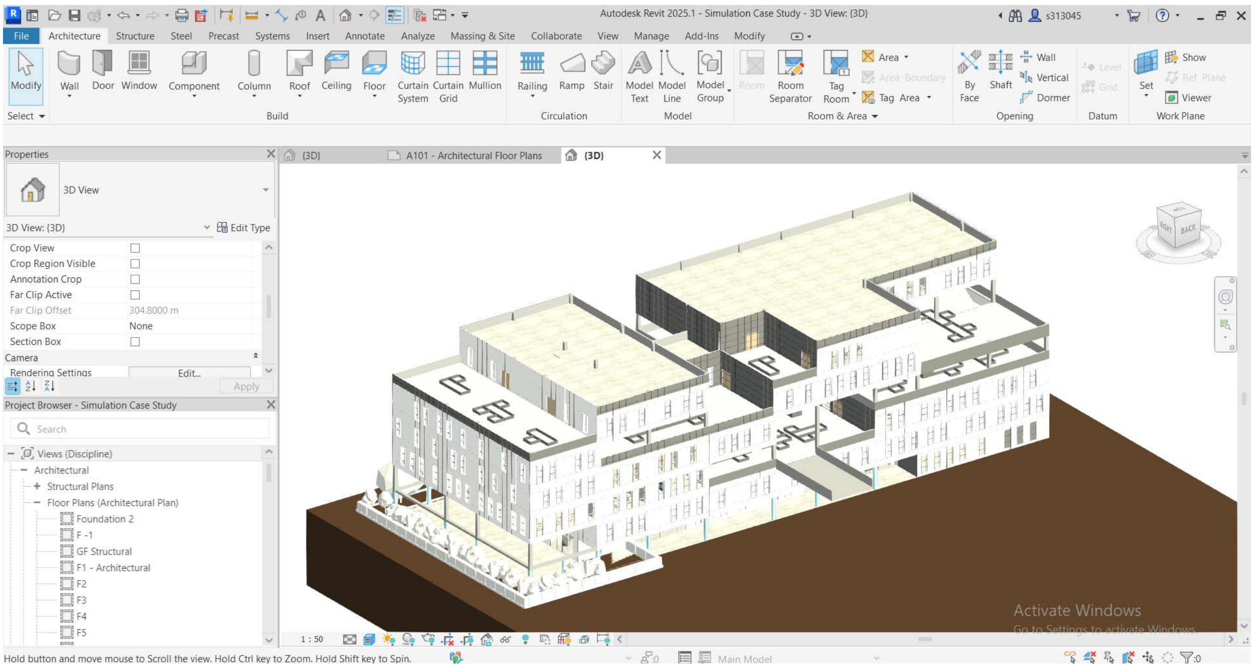


Figure 5.18: 3D Model in Revit after applying changes, Elaborated by Authors

Sahar (BIM) was able to complete this step in a shorter period of time.

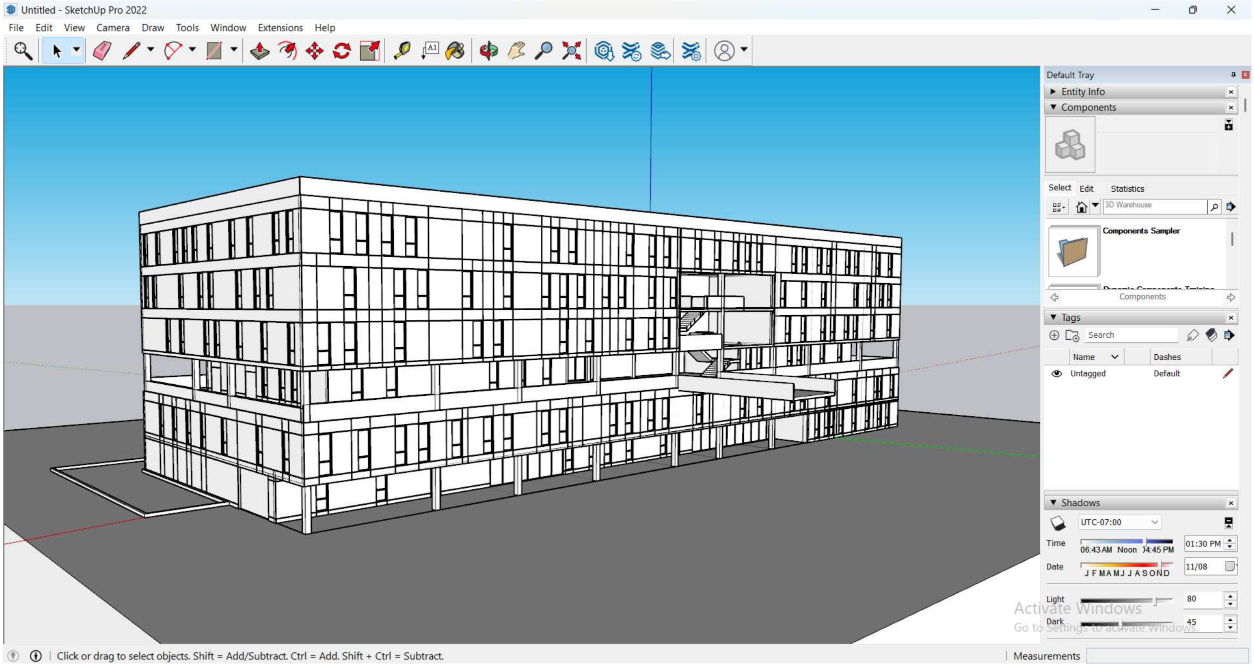


Figure 5.19: 3D Model in SketchUp before applying changes, Elaborated by Authors

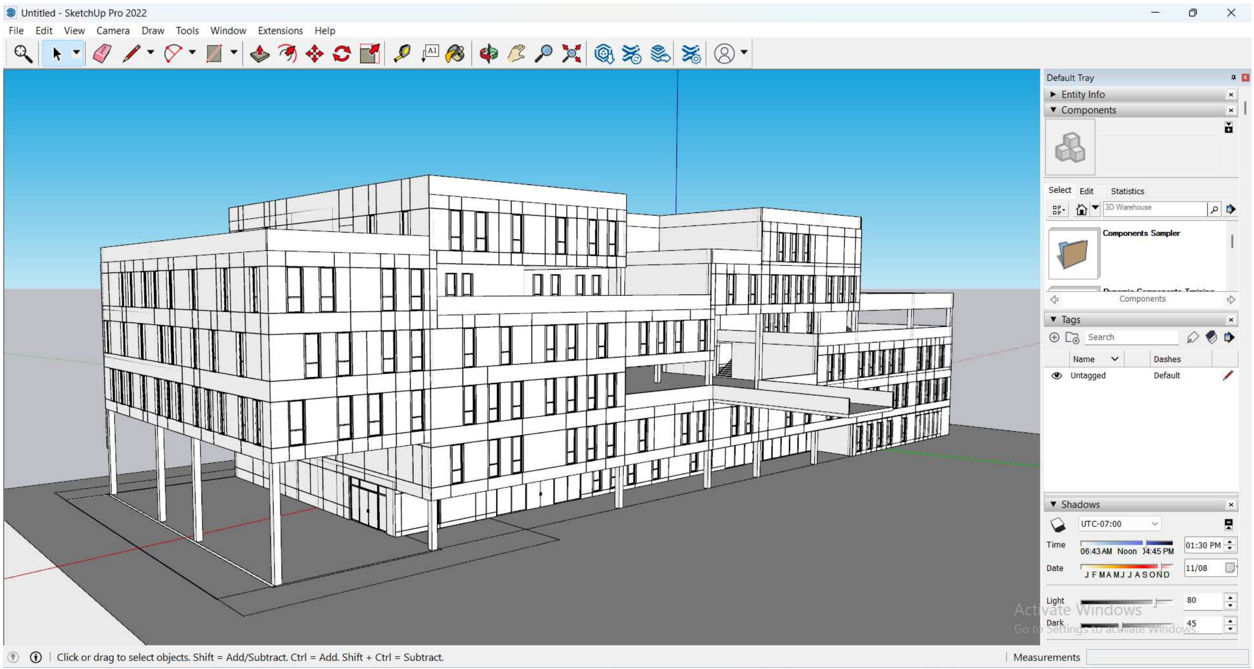


Figure 5.20: 3D Model in SketchUp after applying changes, Elaborated by Authors

Behrad (CAD) also completed this step, but it took twice as long compared to the Revit workflow.

Day 2: Plan Revisions

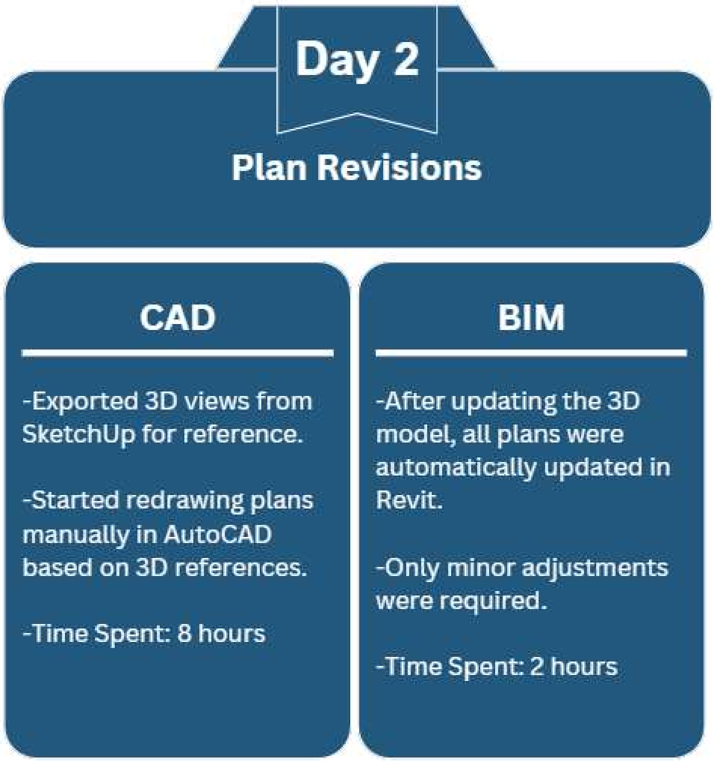


Figure 5.21: Day 2 summary, Elaborated by Authors

With the 3D model updates completed, we moved on to revising the floor plans to reflect the changes.

Behrad (CAD) exported updated 3D views from SketchUp and manually redrew the plans in AutoCAD to match the changes. This process required constant back-and-forth between SketchUp and AutoCAD, ensuring the updates were accurate. (Time Spent: 8 hours)

Sahar (BIM), on the other hand, noticed that Revit automatically updated the plans as soon as the 3D model was modified. She only had to make minor manual adjustments where necessary. (Time Spent: 2 hours)

This stage showed a major time-saving advantage of BIM, as parametric linking allowed seamless plan revisions. In contrast, CAD's manual nature made the workflow inefficient and prone to inconsistencies.

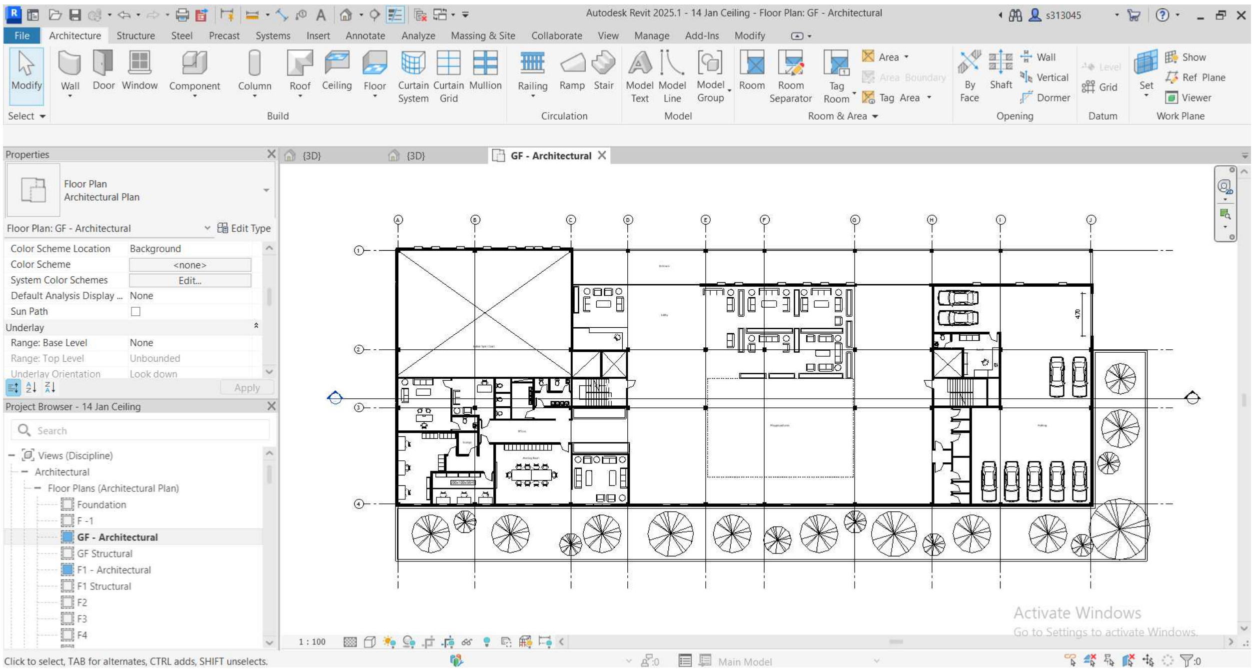


Figure 5.22: Ground floor plan in Revit before applying changes, Elaborated by Authors

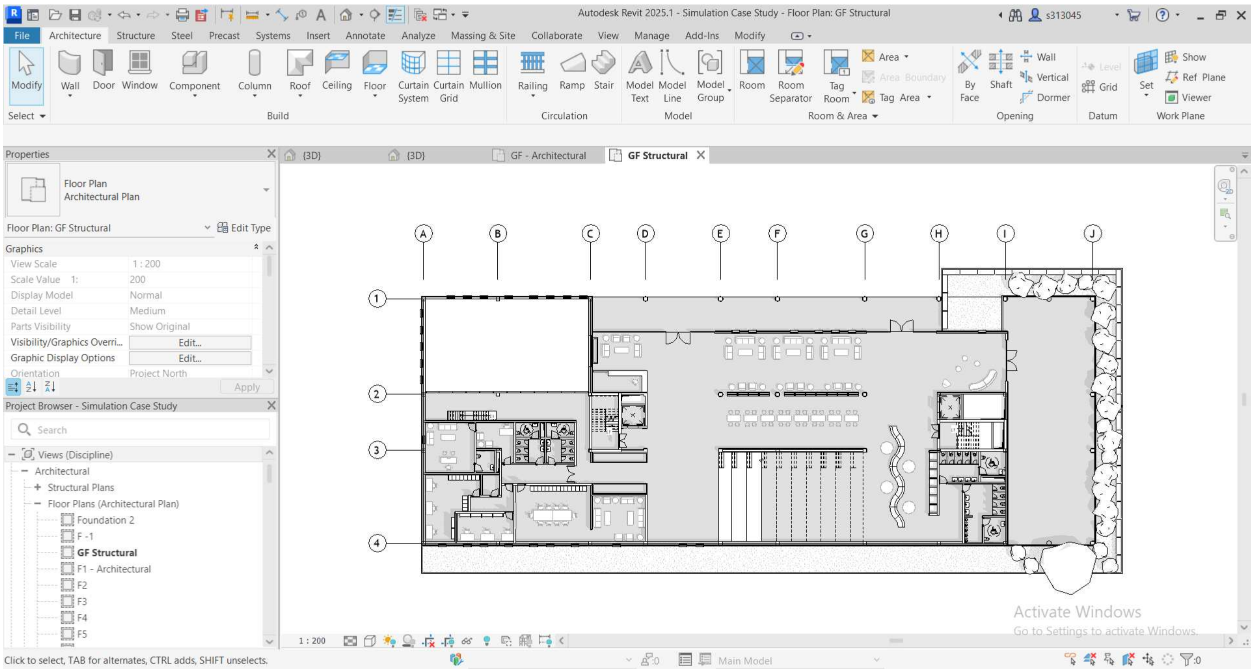


Figure 5.23: Ground floor plan in Revit after applying changes, Elaborated by Authors

Sahar (BIM) managed to finalize the plans and also add furniture.

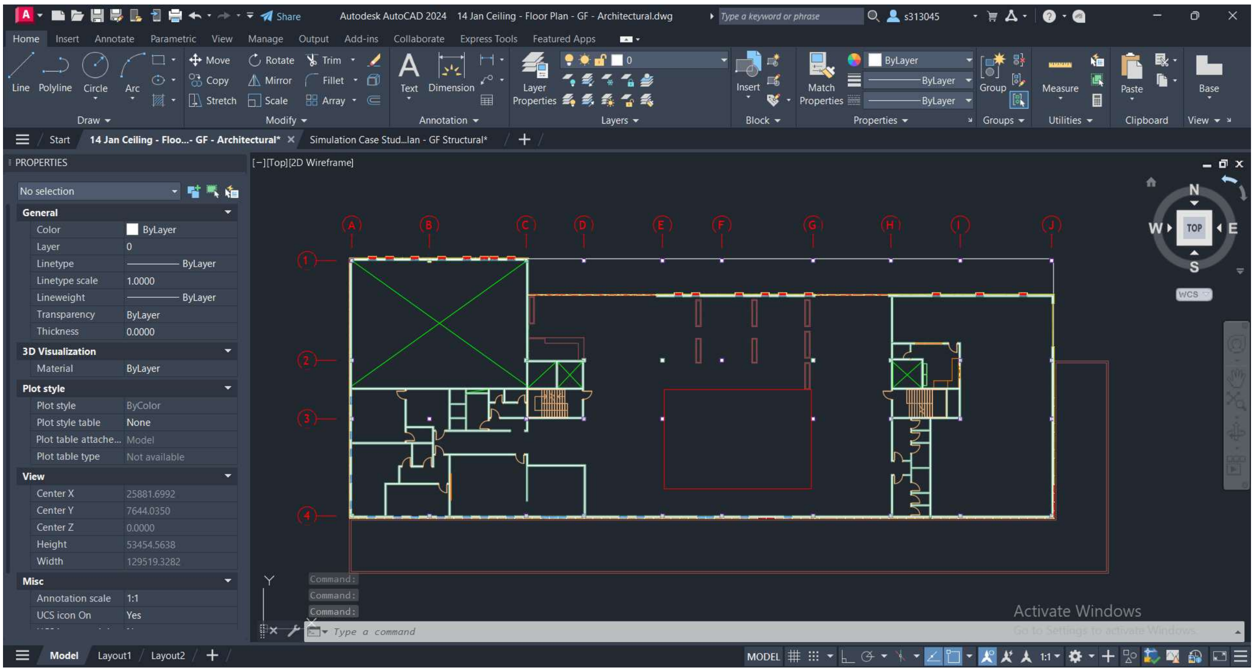


Figure 5.24: Ground floor plan in AutoCAD before applying changes, Elaborated by Authors

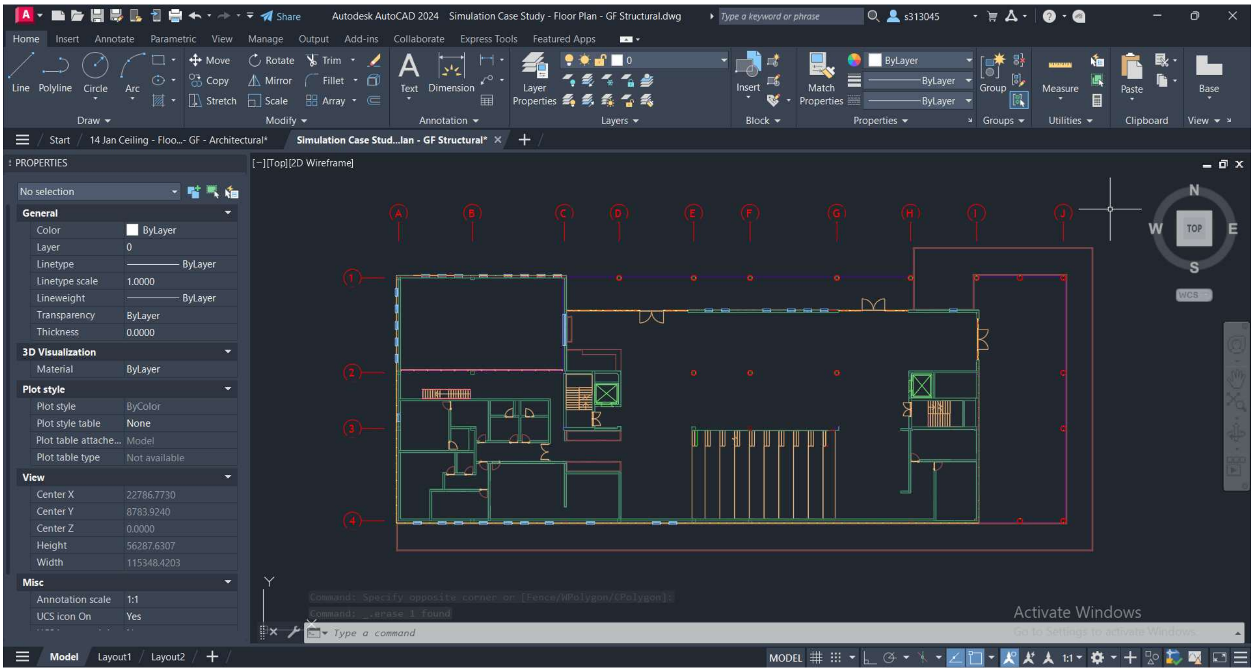


Figure 5.25: Ground floor plan in AutoCAD after applying changes, Elaborated by Authors

Behrad (CAD) managed to edit the plans but was unable to add all the furniture.

Day 3: Section Updates

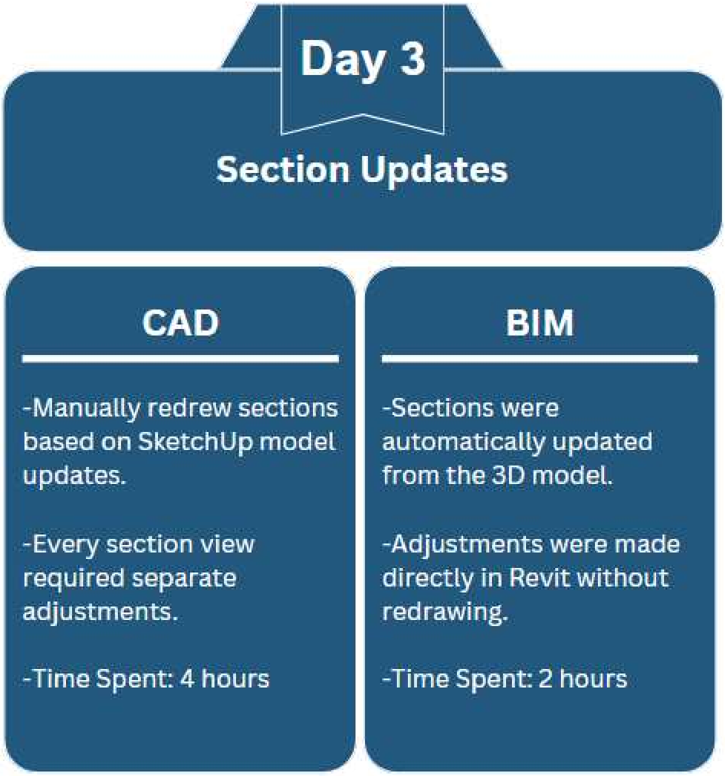


Figure 5.26: Day 3 summary, Elaborated by Authors

Once the floor plans were revised, we proceeded with updating the sections of the project.

Behrad (CAD) manually redrew all section views in AutoCAD, which required significant time and effort since there was no automatic linking between the 3D model and the 2D sections. (Time Spent: 4 hours)

Sahar (BIM), using Revit, automatically updated the sections from the model, requiring only minor refinements. (Time Spent: 2 hours)

Again, Revit's automated updating of sections provided a clear efficiency boost, whereas AutoCAD required manual coordination between model updates and drawing adjustments.

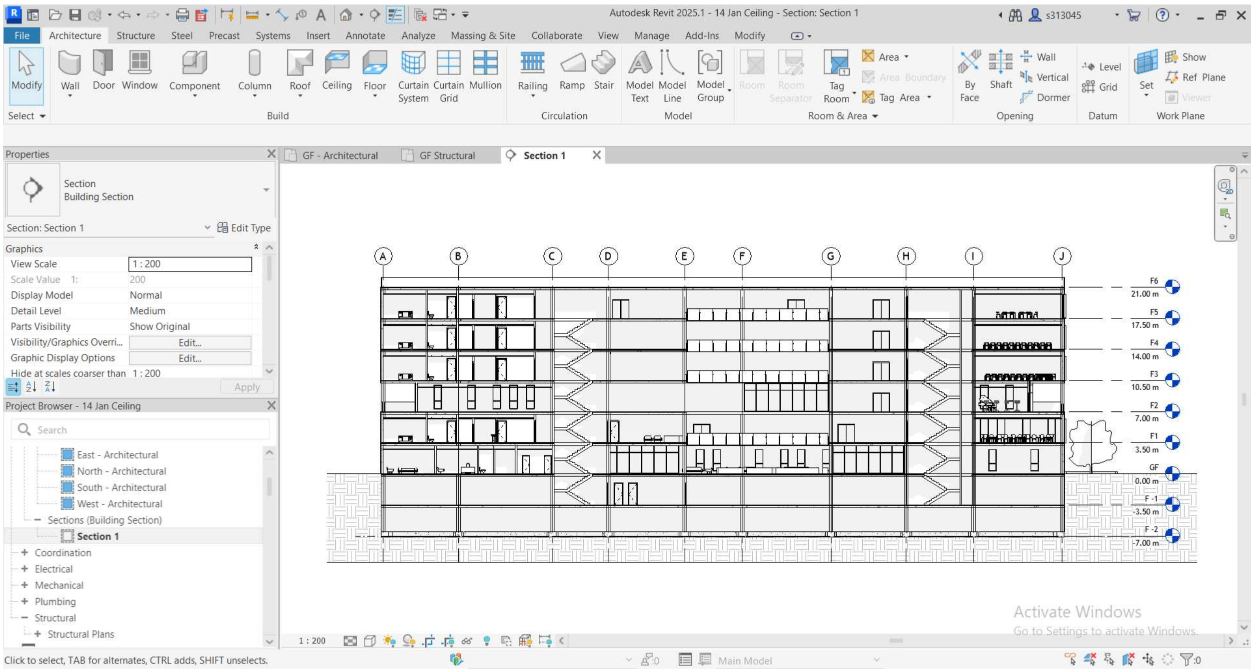


Figure 5.27: A Section in Revit before applying changes, Elaborated by Authors

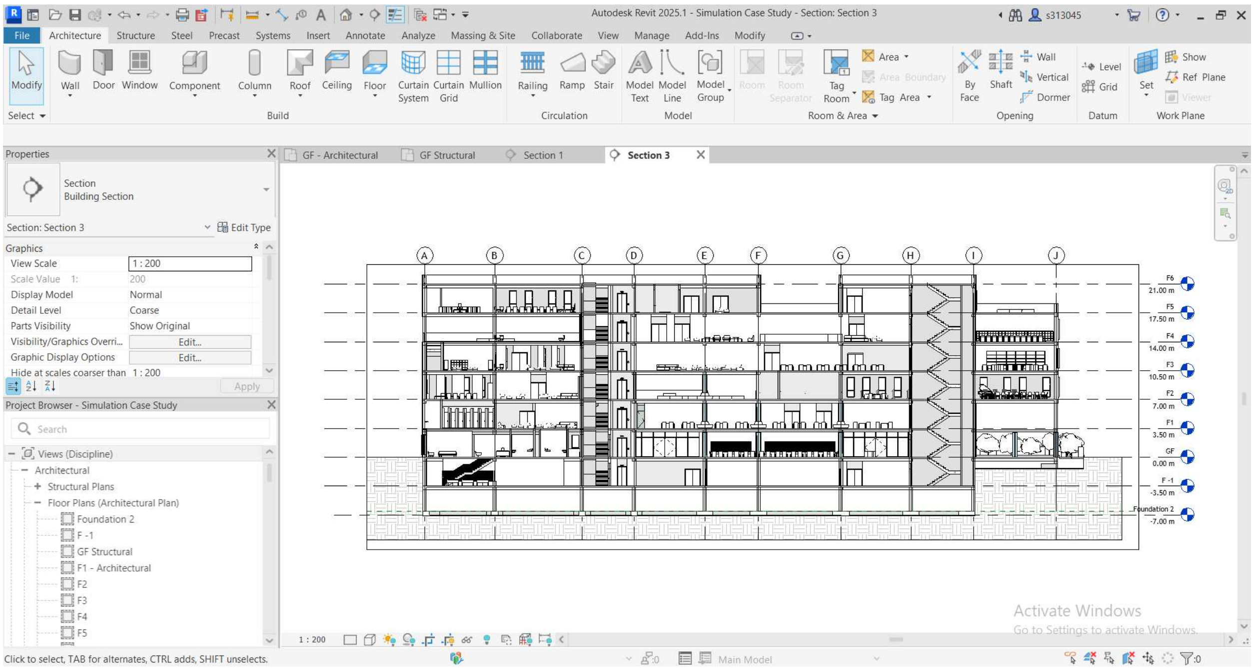


Figure 5.28: Auto-updated Section in Revit after applying changes on 3D model and plans, Elaborated by Authors

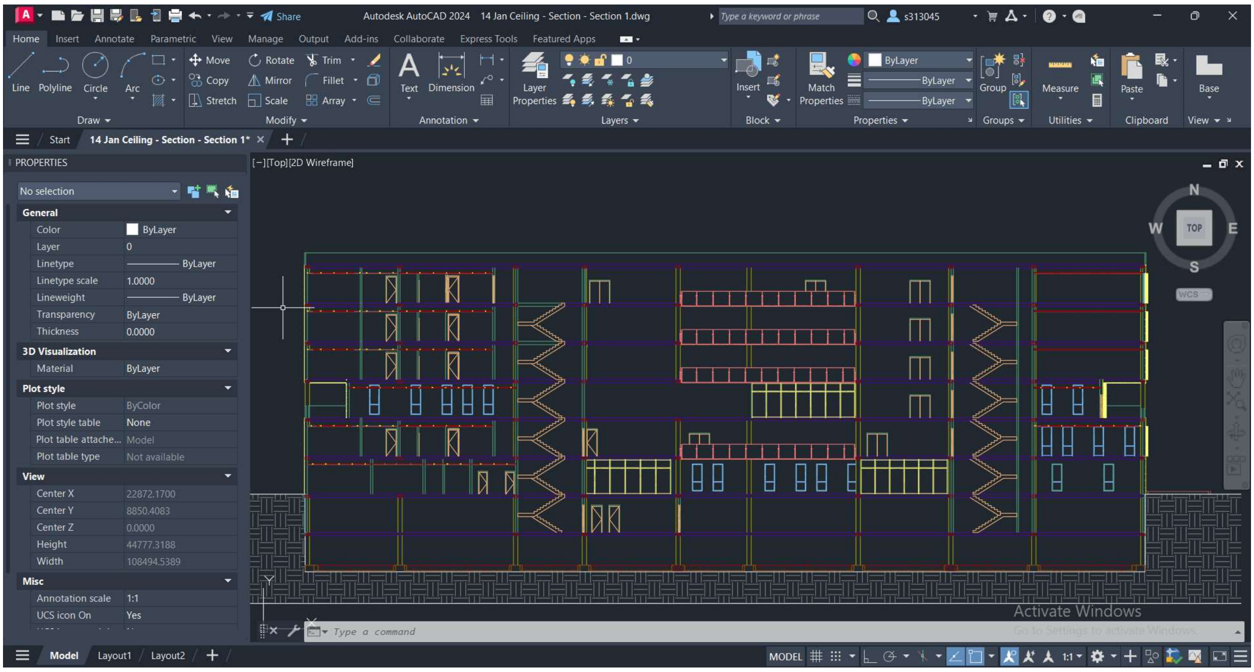


Figure 5.29: A Section in AutoCAD before applying changes, Elaborated by Authors

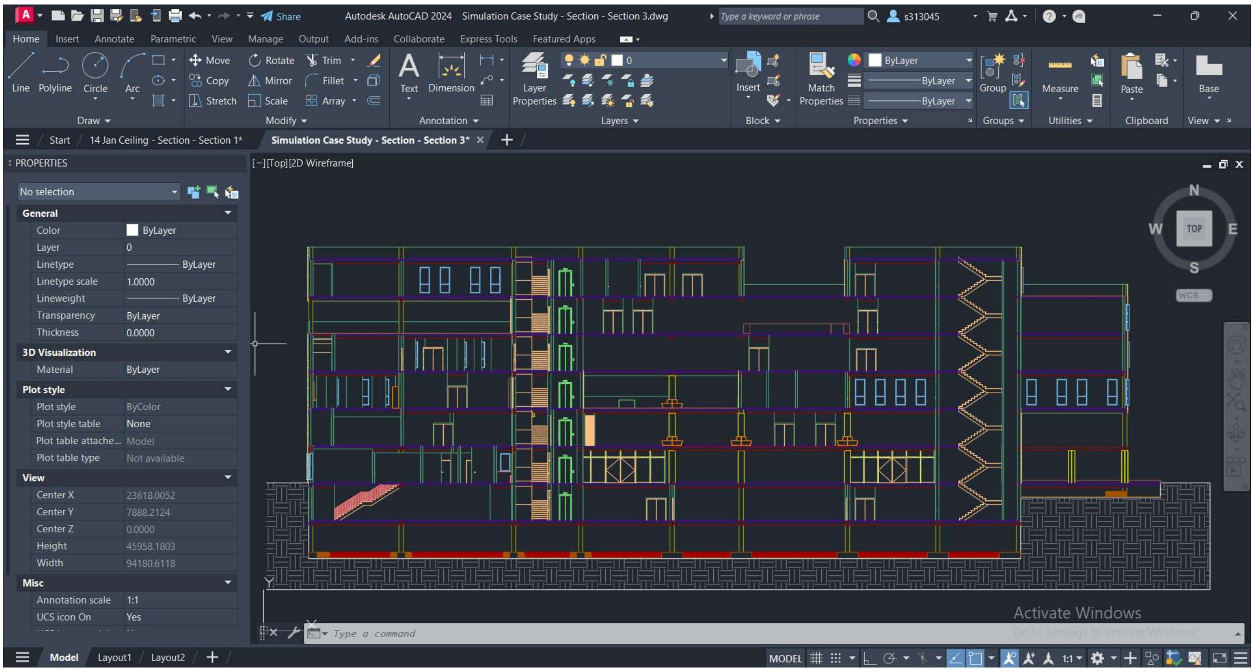


Figure 5.30: The Section in AutoCAD after editing, Elaborated by Authors

In Revit, sections were automatically updated after editing the 3D model and plans, whereas in the CAD workflow, Behrad had to manually redraw the sections from scratch, making the process significantly more time-consuming.

Day 4: Elevation Updates

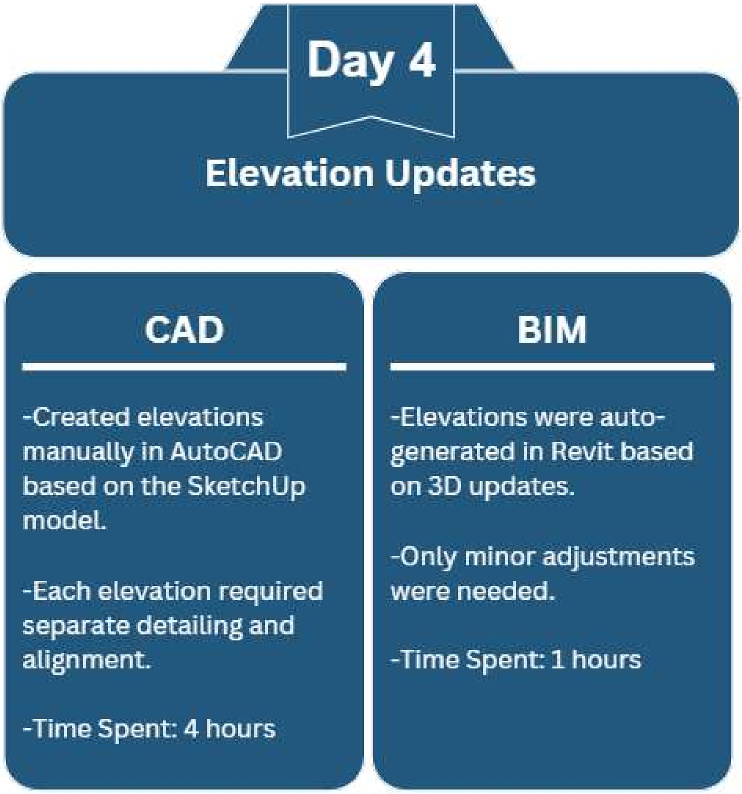


Figure 5.31: Day 4 summary, Elaborated by Authors

Following the section updates, we revised the elevations to match the model changes.

Behrad (CAD) manually created elevations in AutoCAD, aligning them with the SketchUp model and ensuring accurate placement of elements. (Time Spent: 4 hours)

Sahar (BIM) had the elevations auto-generated from the Revit model, requiring only minor visual refinements. (Time Spent: 1 hours)

At this point, it was evident that BIM significantly reduced redundant work. While Behrad had to recreate each elevation, Sahar only had to verify automatically generated views, making the process much more efficient.

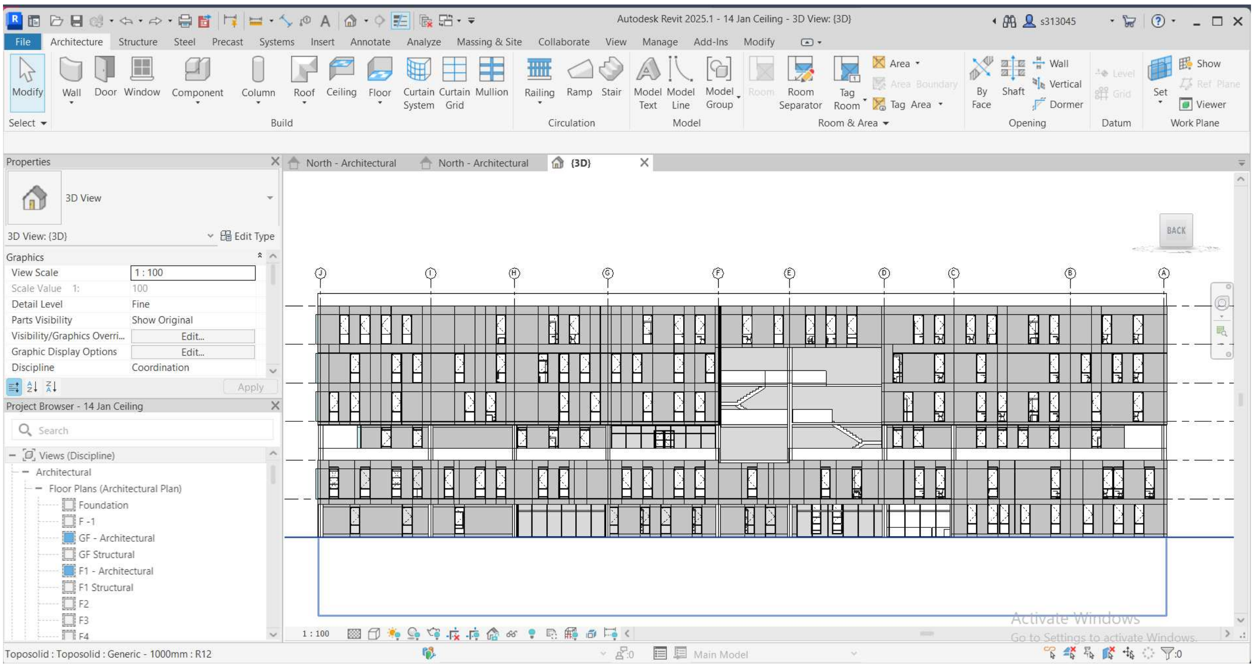


Figure 5.32: North Elevation in Revit before applying changes, Elaborated by Authors

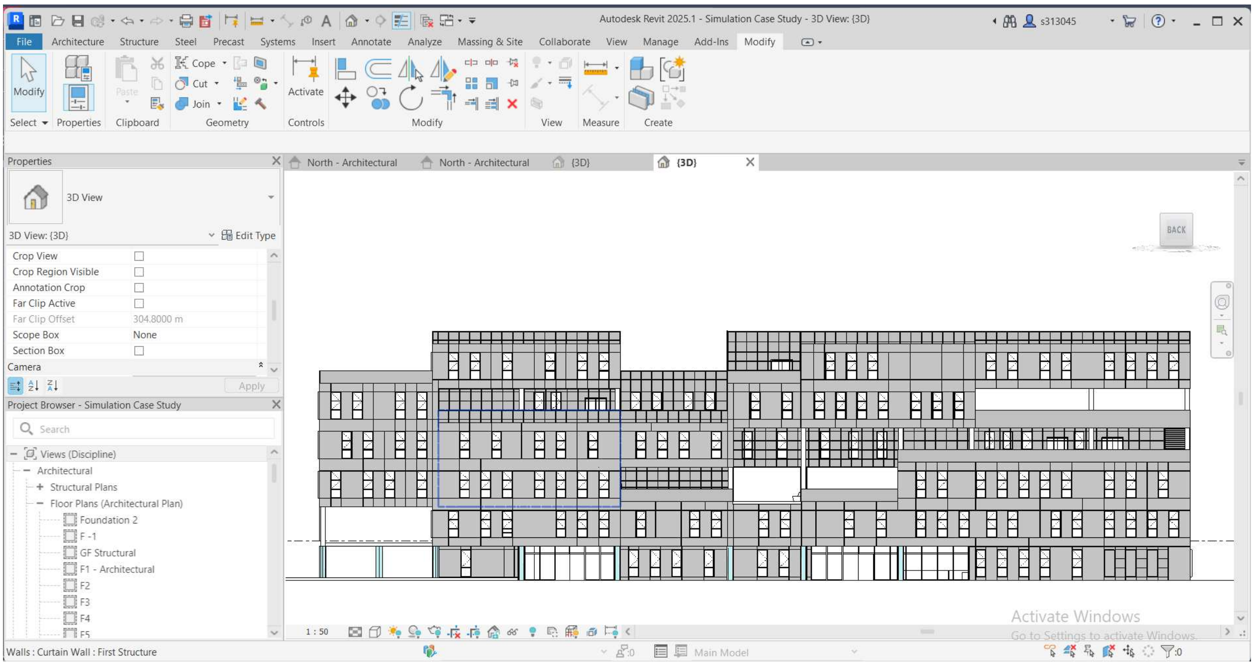


Figure 5.33: North Elevation in Revit after editing plans and 3d model, Elaborated by Authors

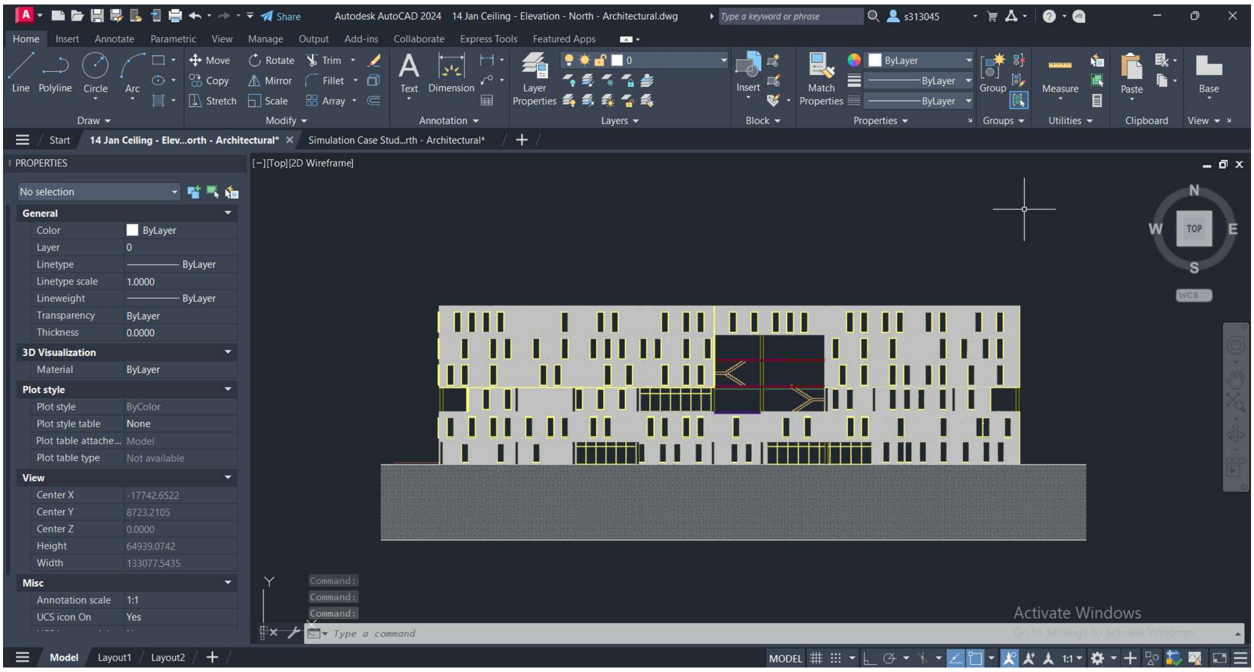


Figure 5.34: North Elevation in AutoCAD before editing, Elaborated by Authors

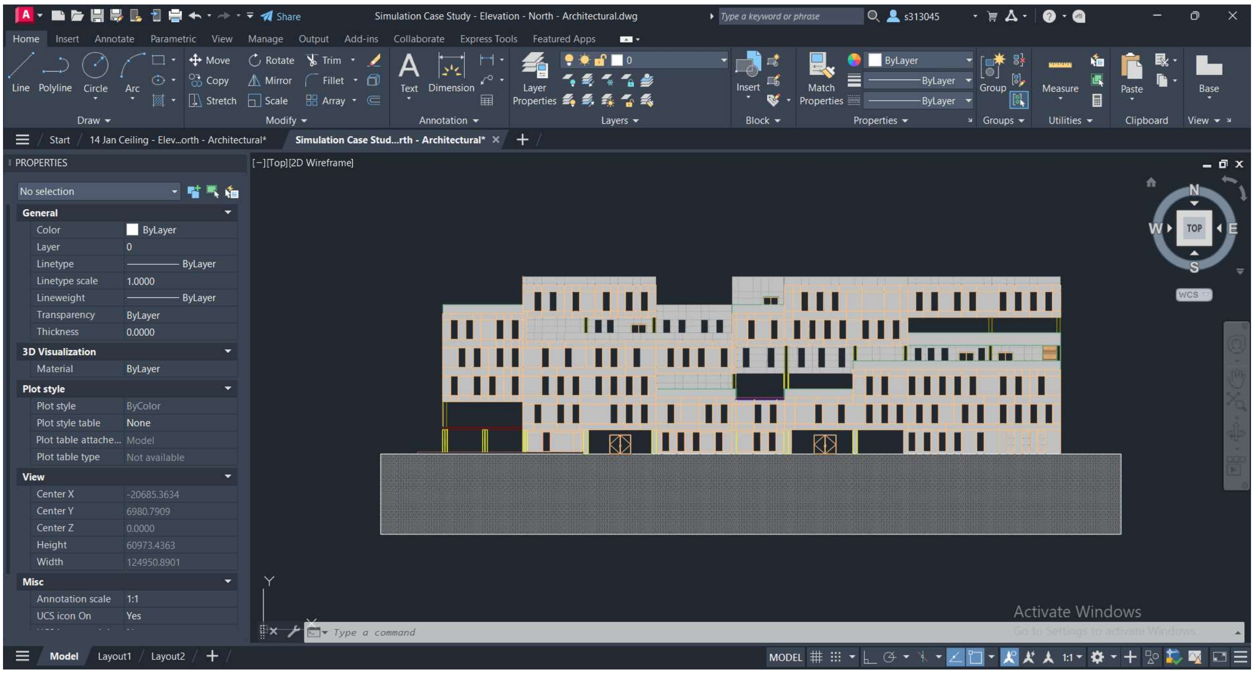


Figure 5.35: North Elevation in AutoCAD after editing, Elaborated by Authors

In Revit, after updating the 3D model and plans, the elevations were automatically adjusted, eliminating the need to redo the facade detailing. In contrast, in AutoCAD, Behrad had to manually redraw the elevations and recreate the facade details, making the process significantly more time-consuming.

Day 5: Clash Detection

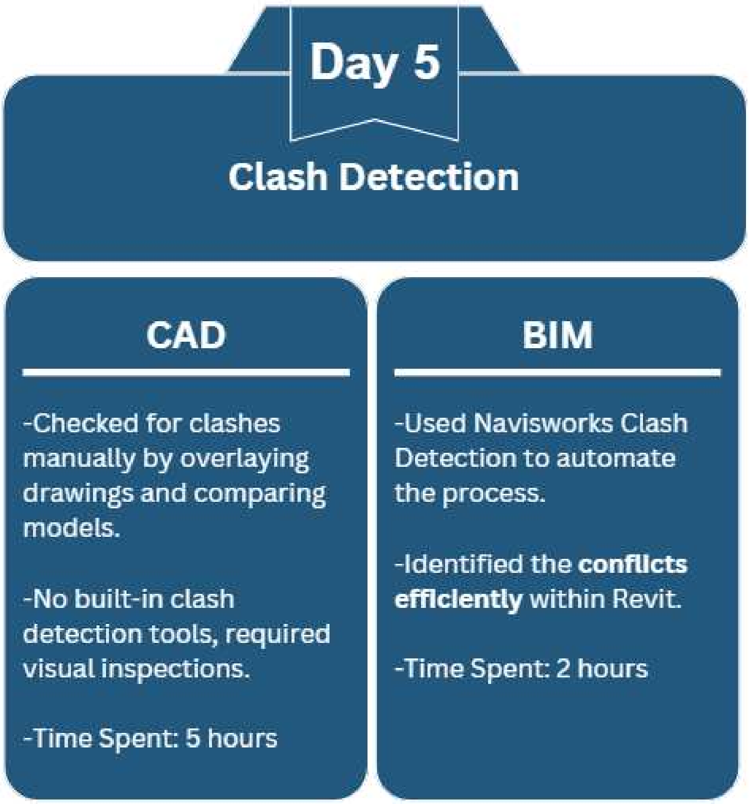


Figure 5.36: Day 5 summary, Elaborated by Authors

Once the design updates were complete, we decided to detect clashes and conflicts between architectural and structural elements.

Behrad (CAD) manually compared AutoCAD floor plans and SketchUp 3D views to identify potential clashes between floors and structural columns. This process involved visually scanning and overlaying different files. (Time Spent: 5 hours)

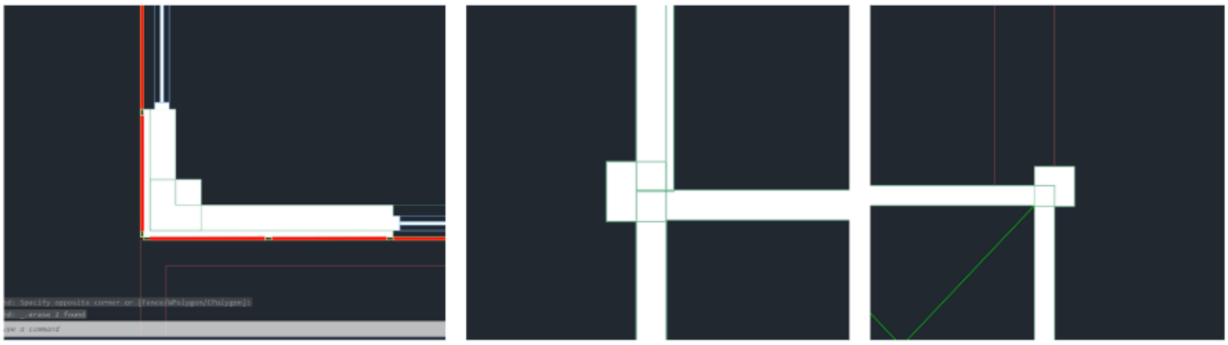


Figure 5.37: Manual conflict detection in AutoCAD, Elaborated by Authors

Sahar (BIM) used Navisworks' clash detection tool, which automatically flagged conflicts between the architectural and structural models. (Time Spent: 2 hours)

Navisworks' clash detection tool reduced the time and effort required, while CAD’s manual process proved to be inefficient and less reliable in detecting all conflicts.

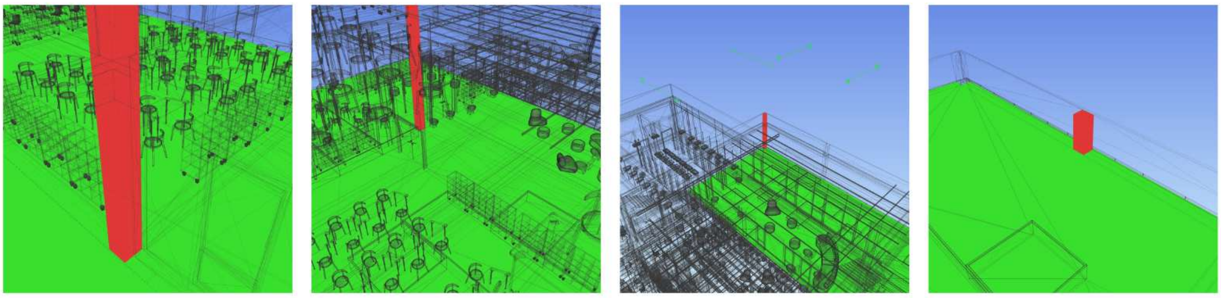


Figure 5.38: Automated clash detection in Navisworks, Elaborated by Authors

Day 6: Final Adjustments

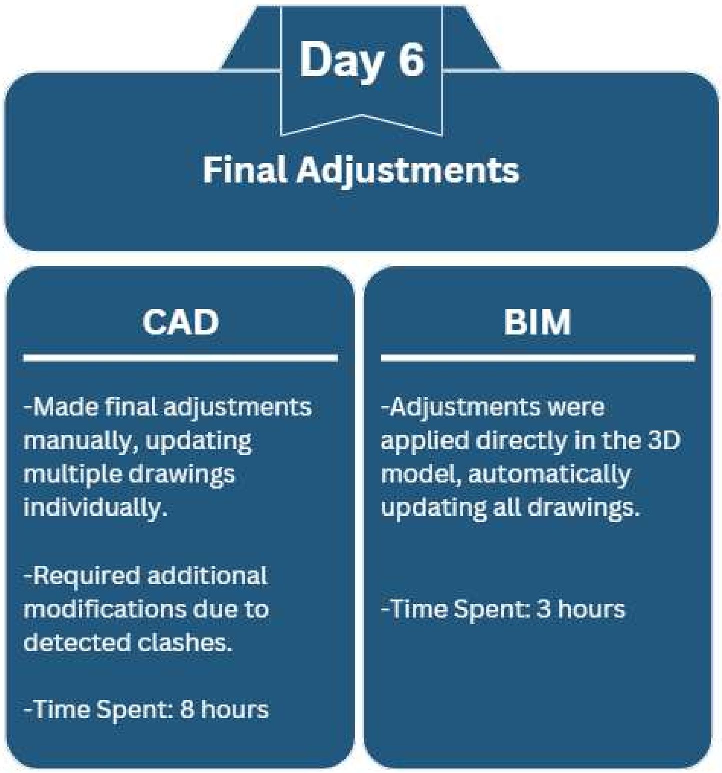


Figure 5.39: Day 6 summary, Elaborated by Authors

After identifying clashes, we implemented final adjustments to the project.

Behrad (CAD) manually updated each drawing, adjusting sections, elevations, and floor plans based on the detected conflicts. This required redoing multiple views to maintain consistency. (Time Spent: 8 hours)

Sahar (BIM) applied changes directly in the 3D model, which automatically updated all associated drawings. (Time Spent: 3 hours)

This phase reinforced BIM's advantage in reducing redundant rework, as Sahar's adjustments automatically updated all related documents.

Day 7: Submission

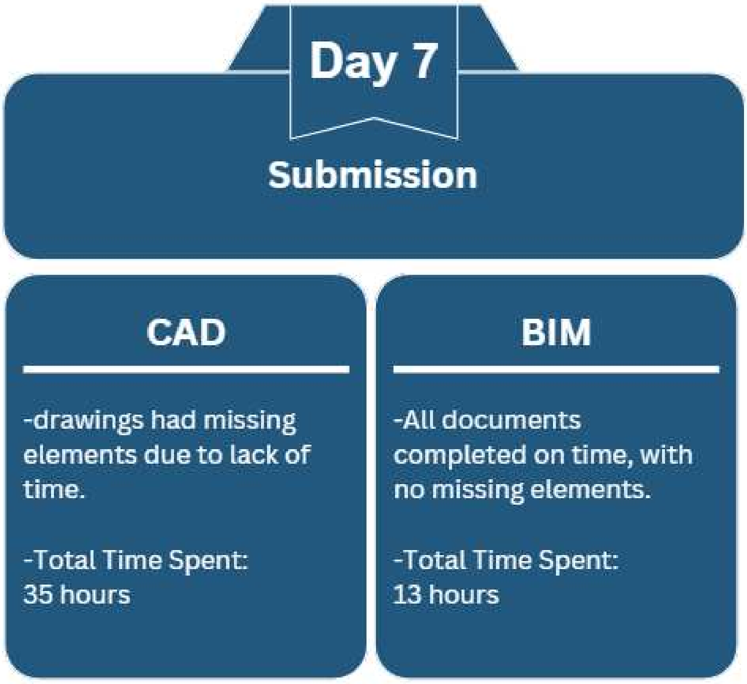


Figure 5.40: Day 7 summary, Elaborated by Authors

Finally, we prepared the final deliverables for submission.

5.3.4.3 Critical Analysis

Behrad (CAD) struggled with incomplete documentation, as the manual updates had delayed progress.

Sahar (BIM) had a fully coordinated and completed submission, thanks to automated updates and clash resolution.

The step-by-step analysis of our simulation highlights the significant advantages of BIM workflows in collaborative AEC projects. By leveraging Revit's real-time synchronization, automated updates, and built-in clash detection, we were able to streamline coordination, reducing both time and effort when compared to the manual, disconnected CAD approach. The quantitative and visual evidence from this study reinforces BIM's ability to enhance productivity, minimize errors, and ensure efficient project delivery.

Throughout this simulation, it became evident that BIM's automation, synchronization, and parametric modeling vastly outperformed the traditional CAD workflow, which relied on manual updates and separate software tools. As a result, Behrad's CAD-based workflow faced time constraints and resulted in incomplete documentation, while Sahar's BIM-based workflow delivered a fully coordinated, finalized submission with greater efficiency.

5.3.4.4 Final Time Comparison:

- Total Time Spent (CAD Workflow - Behrad): 35 hours
- Total Time Spent (BIM Workflow - Sahar): 13 hours
- Total Time Saved Using BIM: Approximately 63% reduction in total effort for these specific tasks.

This simulation clearly illustrates the transformative impact of BIM on interdisciplinary collaboration within AEC projects. By reducing manual labor, enhancing real-time coordination, and improving overall project accuracy, BIM proves to be a crucial tool for modern construction workflows.

5.3.4 Conclusion: Evaluation of Key Parameters in the Simulations

At the beginning of this chapter, we introduced a diagram outlining the key parameters that the simulation aimed to evaluate.

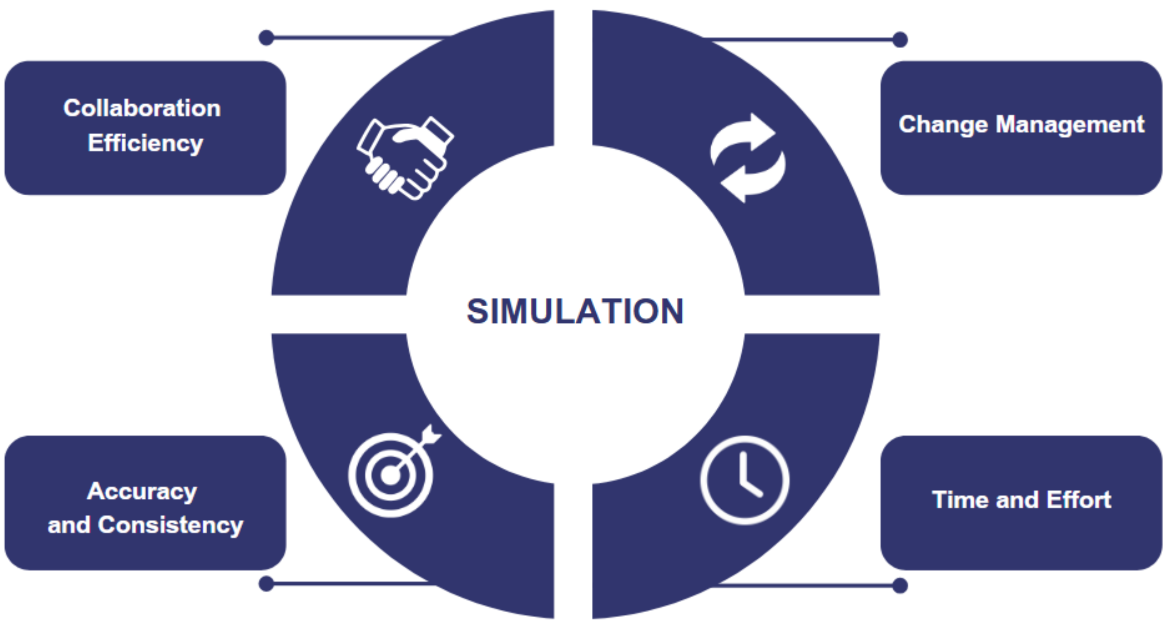


Figure 5.2: Key Parameters of the Simulation, Elaborated by Authors

1. Collaboration Efficiency

The BIM workflow significantly improved collaboration efficiency compared to CAD. In Revit, the collaborate tab, worksets, and synchronization tools allowed both disciplines (architecture and engineering) to work in real time within a shared model. Tasks such as clash detection, change tracking, and communication were streamlined through built-in coordination tools, reducing miscommunication and redundant work. In contrast, the CAD workflow relied on separate files and manual coordination, leading to delays, version control issues, and disconnected processes. Revisions in AutoCAD and SketchUp required multiple file exchanges, whereas Revit's single-source-of-truth approach ensured all updates were reflected instantly across the project.

BIM demonstrated superior collaboration by enabling real-time updates, automated coordination, and seamless communication, reducing workflow inefficiencies.

2. Change Management

Handling design changes and iterative updates was far more efficient in BIM due to its parametric model and synchronized views. In the simulation, Revit automatically propagated changes across plans, sections, and elevations, reducing the need for repetitive manual work. The CAD workflow, however, required separate adjustments for each view, increasing the likelihood of inconsistencies and errors. Behrad (CAD) had to redraw sections and elevations manually each time a design change was made, whereas Sahar (BIM) only needed to adjust the model, and the updates were instantly reflected across all related documents.

BIM significantly reduced the effort required for iterative design changes, eliminating redundancy and ensuring consistency across project views.

3. Accuracy and Consistency

Ensuring accuracy and consistency across multiple project views was a major challenge in the CAD workflow, as each drawing needed separate manual updates, increasing the risk of errors and inconsistencies. The BIM workflow maintained accuracy by linking all drawings to the central 3D model, ensuring that every revision was automatically updated across plans, sections, and elevations. This eliminated gaps between different disciplines, reducing misalignment issues and conflicts. The clash detection tool in Navisworks further enhanced coordination accuracy, allowing early detection of design conflicts.

BIM ensured greater accuracy by maintaining a single source of truth and preventing inconsistencies, while CAD's disconnected workflow increased the potential for errors.

4. Time and Effort

The simulation provided clear quantitative data showing that BIM required significantly less time and effort to complete the same tasks.

- Total time spent in the CAD workflow: 35 hours
- Total time spent in the BIM workflow: 13 hours
- Time saved using BIM: 63% reduction in effort

The largest time savings were observed in plan revisions, clash detection, and final adjustments, where BIM's automation played a crucial role. In contrast, CAD required extensive manual effort to modify, check, and coordinate updates, leading to delays and incomplete documentation.

BIM drastically reduced time spent on repetitive tasks, increasing overall project efficiency and timely completion of deliverables.

The simulations clearly demonstrate that adopting BIM workflows leads to superior project coordination, fewer errors, and faster delivery times compared to traditional CAD-based methods. These findings align directly with the thesis objective of optimizing collaborative practices in the AEC industry.

BIM Advantages	**CAD Limitations**
Automation of updates across all views ensures consistency.	Disconnected workflows lead to inefficiencies and increased workloads.
Real-time synchronization enhances collaboration and reduces delays.	Higher likelihood of errors due to manual recalculations and updates.
Integration of architectural and mechanical systems in a shared model minimizes clashes and design conflicts.	Iterative design changes are harder to manage, often requiring entire workflows to restart.

Table 5.3: BIM Vs. CAD Conclusion, Elaborated by Authors

Chapter 6

6. Case Study, Designing the Extension of the Yuan Ding Middle School

6.1 Introduction and Site Analysis

6.1.1 Project Overview and Objectives

As already mentioned in the introduction, during Behrad Zolfagharzade's internship at the China Room Polito, he had the opportunity to contribute to two projects that are part of the Nanshan 100 Campus Renewal Plan Initiative. This initiative aims to modernize and enhance educational facilities across Shenzhen, Guangdong province, addressing the challenges posed by growing urban populations, aging infrastructure, and evolving educational standards (Preti, 2024). The plan has gathered international attention for its innovative approach to educational renewal, emphasizing energy efficiency, modernization, and urban integration (Preti, 2024).

As part of this experience, Behrad was introduced to the Yuan Ding Middle School, one of the schools included in this renewal plan. Located in Shenzhen's Nanshan district, Yuan Ding Middle School exemplifies the challenges and opportunities faced by educational institutions in rapidly urbanizing regions. The renewal initiative for this school focuses on upgrading existing facilities to better meet contemporary educational needs while replacing or improving outdated structures. The design of the school's renewal was a collaborative effort involving the Politecnico di Torino China Room research group, TDH (Turin Design Hub), Urban Elephant, and the company in charge of the executive design, combining expertise from multiple teams to address the unique needs of the project (Preti, 2024).

Adjacent to the current school lies an **undeveloped plot of land** identified by the school as **a potential site for expansion**. This vacant area presents a unique opportunity to extend the school's facilities, addressing the increasing student population and enhancing the overall functionality of the campus. The conceptualized extension includes additional classrooms, administrative spaces, recreational areas, and more, designed to cater to both current needs and future growth. The proposed design seeks to integrate with the existing school infrastructure, maintaining a cohesive architectural identity while optimizing spatial and functional elements of the campus.

6.1.2 Site Context and Constraints

The site for the Yuan Ding Middle School extension is located on **Nannong Road, Nanshan District, Shenzhen**, within a dense urban setting that has been experiencing rapid growth and modernization. As part of the broader **Nanshan 100 Campus Renewal Plan**, this site presents both opportunities and challenges for the proposed expansion, requiring careful integration with the existing school and the surrounding urban fabric.

The **Nanshan District** is one of Shenzhen's key educational and technological hubs, known for its well-developed infrastructure and proximity to research institutions, innovation centers, and high-density residential areas. The school is situated in a **mixed-use neighborhood**, with commercial buildings, residential complexes, and other educational facilities nearby.

Figure 6.1: Site location, Credits: Urban Elephant

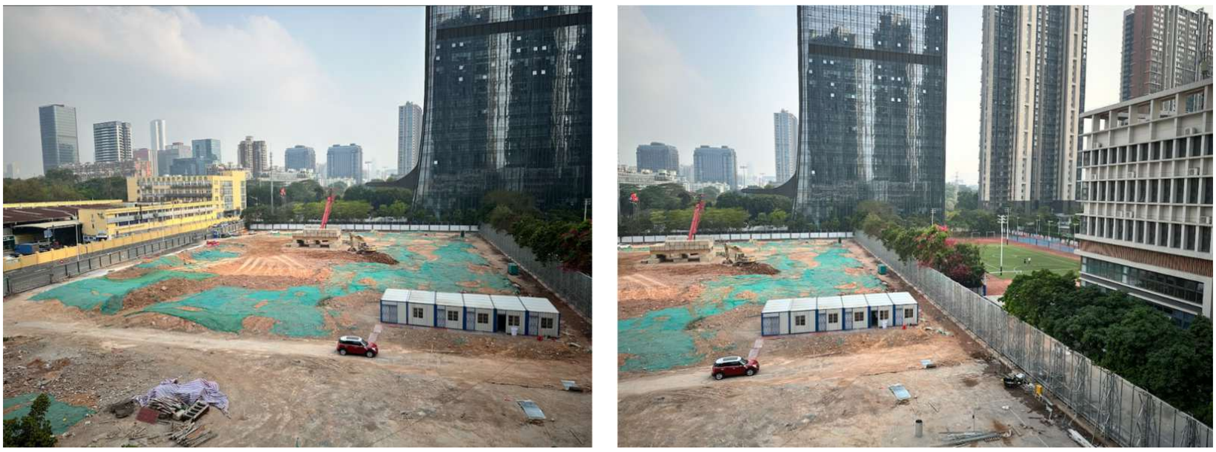


Figure 6.2: The undeveloped plot of land identified by the school as a potential site for expansion, Credits: Urban Elephant

Figures 6.3 and 6.4 present visualizations of the Yuan Ding School renewal design plan, showcasing the proposed enhancements and architectural vision developed by Torino Design Hub.

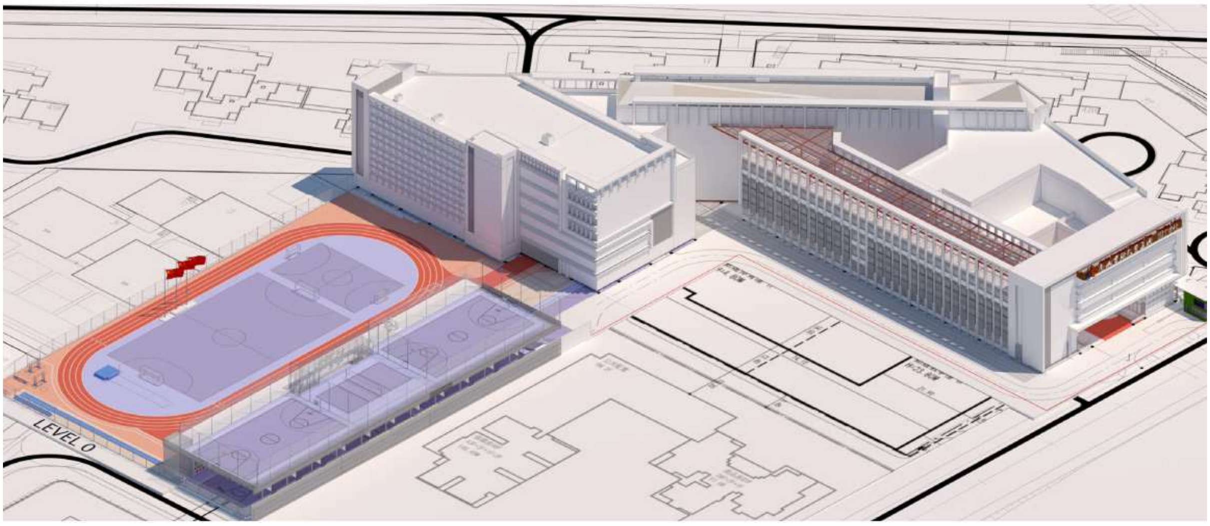


Figure 6.3: Yuan Ding School Renewal Design, Credits: Torino Design Hub

Figure 6.4: Yuan Ding School Renewal Design, Credits: Behrad Zolfagharzade for China Room and Torino Design Hub

6.1.3 Site Analysis Using Rhino, Grasshopper, Ladybug Plugin

The environmental analysis of the Yuan Ding Middle School extension site was conducted using Rhino, Grasshopper, and the Ladybug plugin, focusing on key climatic factors such as shadow projection, solar exposure, air temperature, wind behavior, and direct sun hours. This analysis can be helpful in optimizing building orientation, facade design, passive cooling strategies, and daylighting considerations.

6.1.3.1 Shadow Analysis

The shadow analysis was conducted to study the impact of surrounding buildings on daylight access at different times of the day and across various seasons. The high-rise structures in the vicinity create significant shadow zones, reducing direct sunlight exposure in certain areas of the site. The results suggest that the new extension should be carefully positioned to optimize natural lighting while avoiding excessive overheating. Key takeaway: Shadow patterns must be considered for classroom placement, ensuring that learning spaces receive adequate daylight without causing glare issues.

Animation1:
https://drive.google.com/file/d/1sWUPmcl3Syun_MKi3ROf9ZNGX8voZTo_/view?usp=sharing

Animation 2:
https://drive.google.com/file/d/1eq1RLboz2CwqeM-mi4kpBkAdxW59CSk7/view?usp=sharing

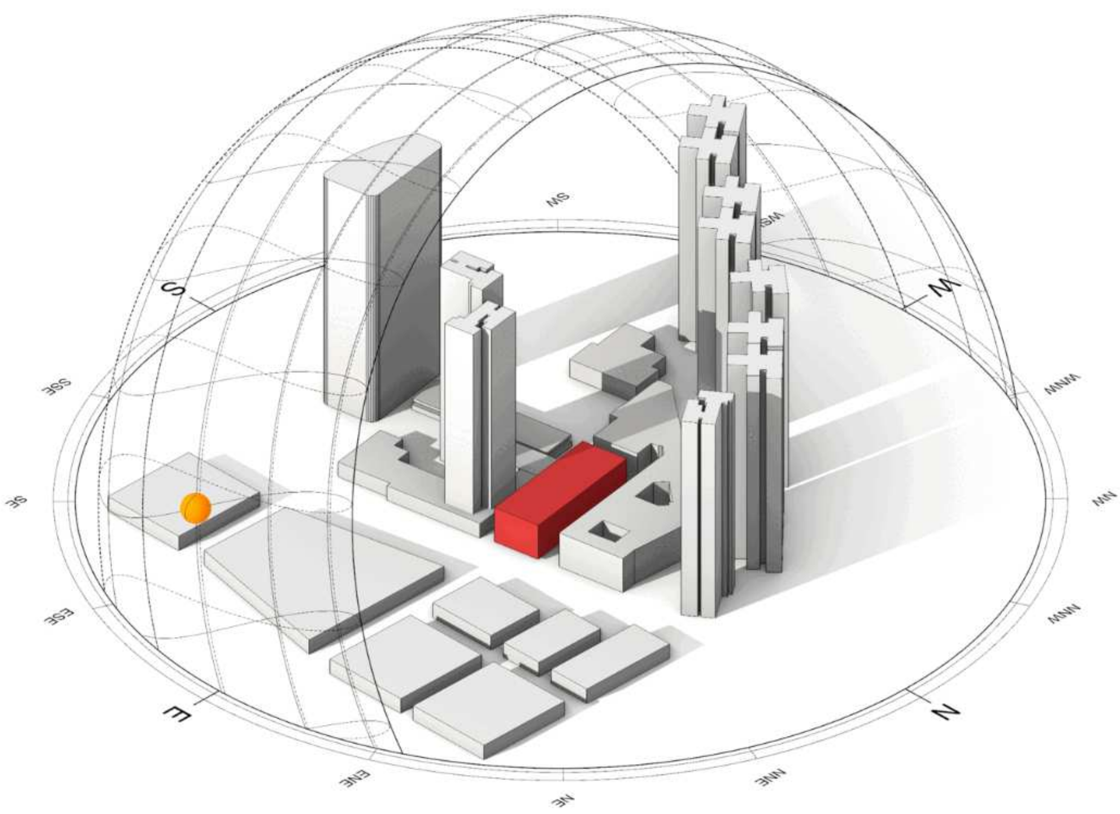


Figure 6.5: Shadow Analysis using Grasshopper, Elaborated by authors

6.1.3.2 Solar Analysis

The Direct Sun Hours diagram illustrates the distribution of sunlight exposure across the site throughout the year. The analysis reveals that while some areas, particularly open spaces, receive moderate to high solar radiation, the overall exposure is not excessive.
Areas in yellow and red indicate higher solar exposure, while blue and purple zones represent shaded or low-exposure areas.
Due to the presence of high-rise buildings around the site, parts of the school experience partial shading, reducing the overall solar impact.

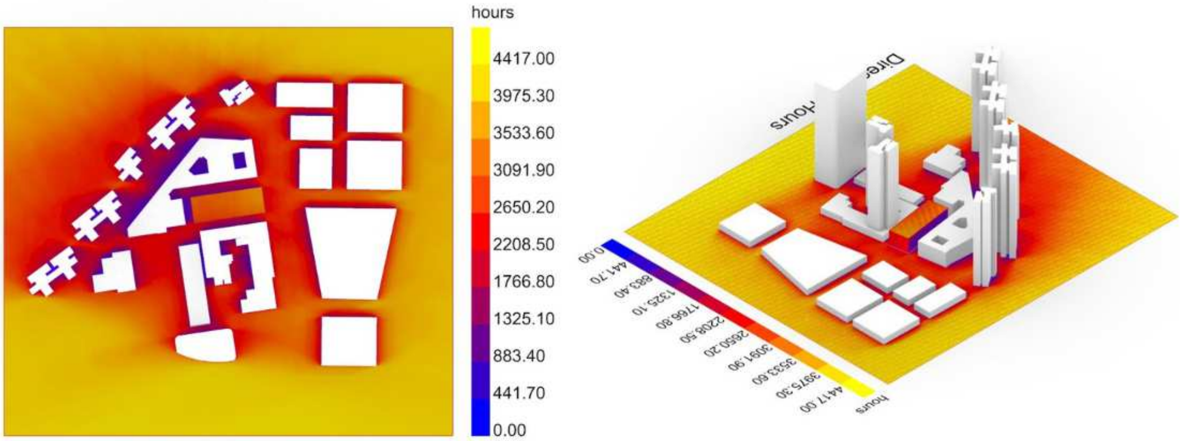


Figure 6.6: Direct sun hours diagrams, Analysis using Grasshopper, Elaborated by authors

6.1.3.3 Dry Bulb Temperature Analysis

The first diagram shows the daily temperature variations throughout the year, indicating that Shenzhen experiences high temperatures, particularly between May and September.

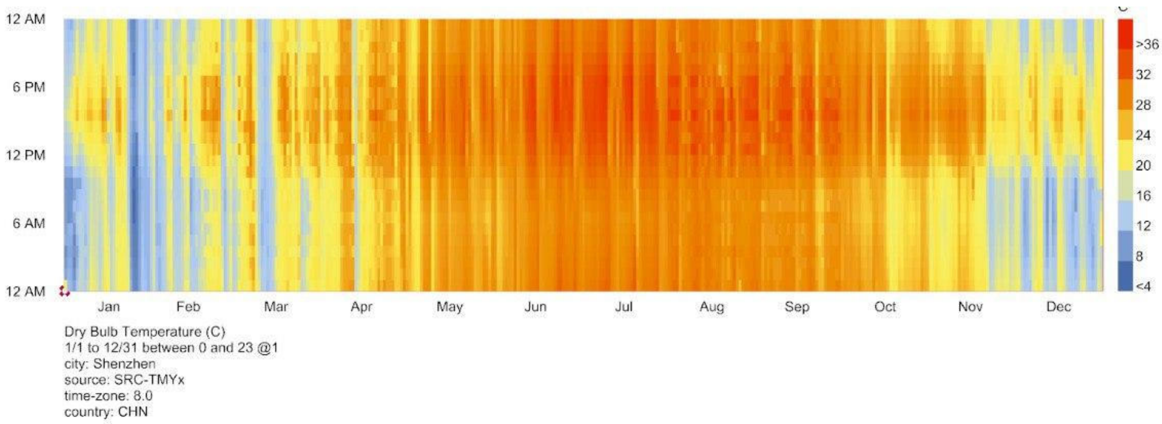


Figure 6.7: Dry Bulb Temperature Analysis using Grasshopper, Elaborated by authors

The second diagram highlights monthly average temperatures, peaking around July-August (~30°C) and dropping in December-January (~14°C).

Figure 6.8: Dry Bulb Temperature Analysis using Grasshopper, Elaborated by authors

6.1.3.4 Wind Direction and Speed Analysis

The wind rose chart illustrates prevailing wind directions and wind speeds throughout the year. Shenzhen experiences dominant winds from the northeast (NE) and east-northeast (ENE) directions, with speeds mostly below 8 m/s.

The school extension can be oriented to take advantage of prevailing winds for natural ventilation. Open spaces should be designed to capture cooling breezes, improving indoor comfort.

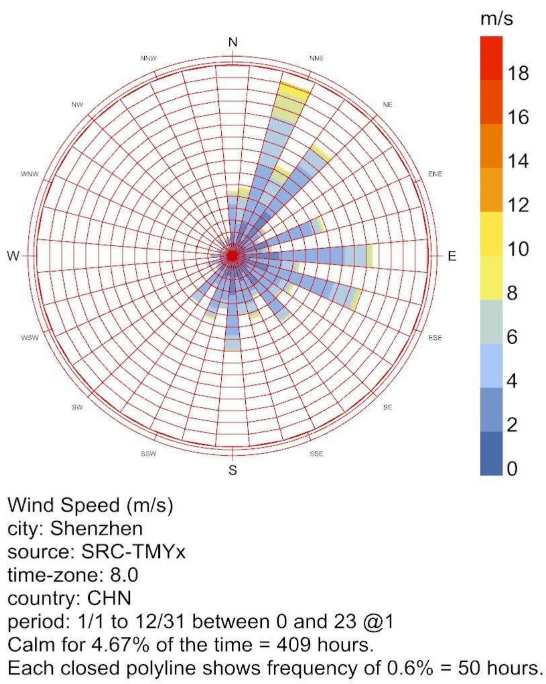


Figure 6.9: Wind Rose diagram made by Ladybug, Grasshopper, Elaborated by authors

6.2 Conceptual Diagrams

The initial design concept for the **Yuan Ding Middle School extension** was developed considering **site constraints, circulation efficiency, spatial organization, and integration with the existing school**. The design balances **functionality, accessibility, and open public spaces**, ensuring a dynamic and engaging educational environment.

6.2.1 Initial Design Concept

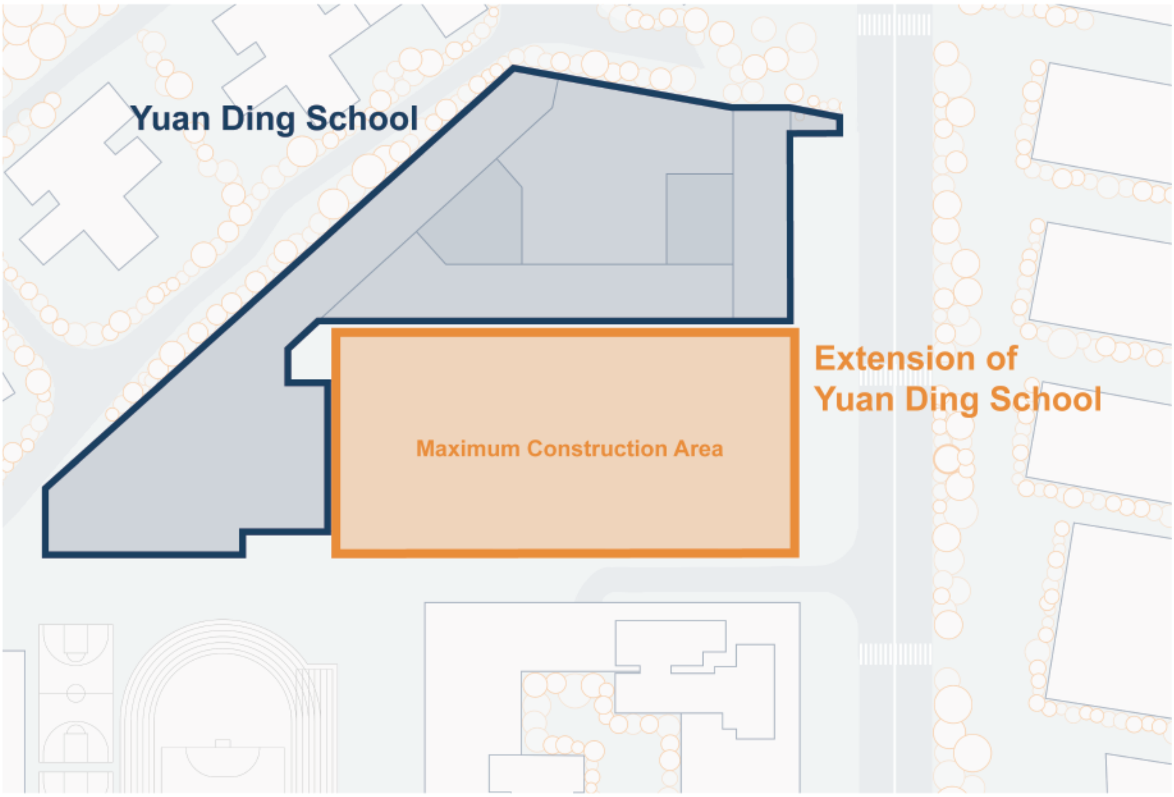
The initial design concept was developed in response to site restrictions, ensuring that the project stays within the maximum construction land of 4,244 square meters.

The building footprint was defined as 28 × 77 meters, totaling 2,156 square meters, establishing the boundary for the new extension. The remaining open space is designated for greenery, landscaping, and accessibility routes, enhancing the outdoor environment while maintaining seamless movement around the school.

A key design intervention is the inclusion of a bridge, which connects the extension to the existing Yuan Ding School, ensuring smooth circulation and fostering a sense of continuity between the old and new facilities.

Key Features of the Initial Concept:

1. Optimized footprint to maximize buildable area while maintaining necessary open space. Integration of green spaces to enhance the school’s microclimate and provide outdoor learning areas.
2. A connecting bridge to facilitate easy access between the existing school and the new extension.

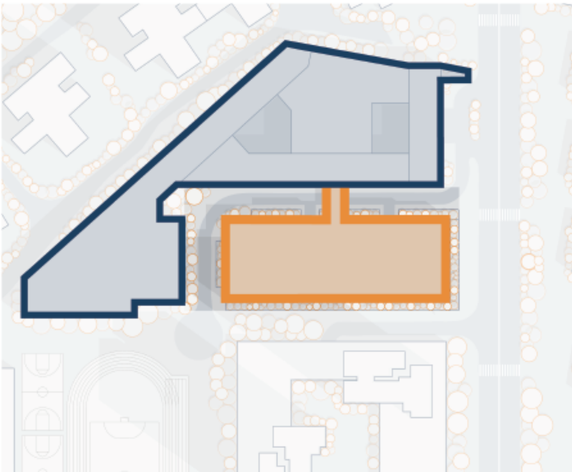


Site Plan of Project

According to site restrictions, the maximum construction land for this project can reach 4,244 square meters.

Proposes Building Construction Area

The building footprint is 28 × 77 meters, totaling 2,156 square meters. This defines the building's perimeter and boundary.



Proposed Building Surronding Area

The remaining space is designated for greenery, trees, and landscaping, along with accessibility roads and entrances for the school extension. Additionally, a bridge is proposed to connect the extension to Yuan Ding School.

Figure 6.10: Site plan conceptual diagram, Elaborated by authors

Integration with Yuan Ding School

A bridge is proposed to connect the new extension with the existing Yuan Ding School, ensuring seamless circulation and accessibility between the two structures. The bridge acts as a functional and symbolic link, enhancing movement while maintaining a cohesive architectural language.

Vertical Organization and Circulation

The design introduces a well-planned vertical circulation system, ensuring efficient movement throughout the building.

Ground & First Floor: Vertical circulation cores strategically positioned for accessibility provide smooth transitions across floors. The ground level focuses on main entrances, student arrival areas, and access routes.

Second Floor: The bridge connection to the existing school is introduced at this level, ensuring direct access between the extension and the main campus. Open public spaces begin to emerge, fostering interaction and social engagement.

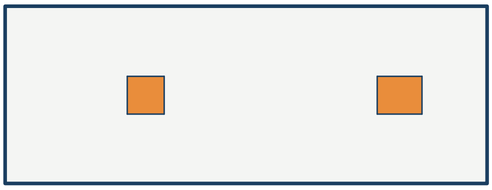
Third Floor: Public spaces expand across the level, encouraging students to utilize different zones during breaks. This design strategy prevents congestion and promotes free movement and engagement.

Fourth & Fifth Floors: Open spaces continue to be distributed across different levels, creating a dynamic, multi-level school environment. The layout reduces overcrowding, ensuring students can gather in smaller, more interactive zones.

The design emphasizes openness, flexibility, and community-driven engagement, making the extension a lively and adaptable educational space.

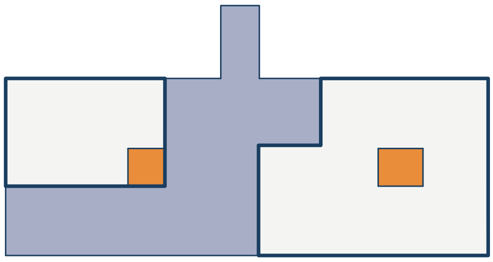
Design Implications

The layered distribution of open public spaces ensures a comfortable, flexible, and student-centered environment. The bridge and circulation core placement optimize connectivity, improving accessibility and functionality. The integration of landscaping, greenery, and open-air areas enhances well-being and sustainability, aligning with modern educational facility standards.



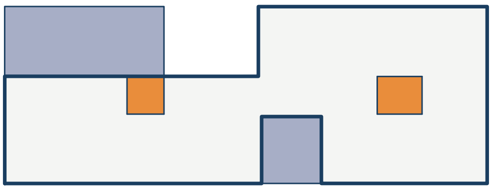
Ground Floor and First Floor

V**ertical circulation** cores, ensuring **connectivity** through all floors. Strategically placed for accessibility, they allow easy and safe access from any point in the building.



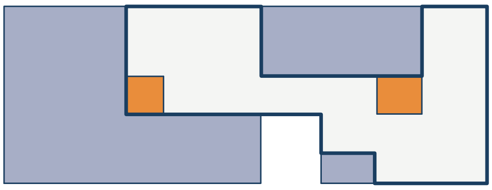
Second Floor

A **bridge** connects the proposed school extension to the Yuan Ding school. Introduction of **open public spaces** begins at this level.



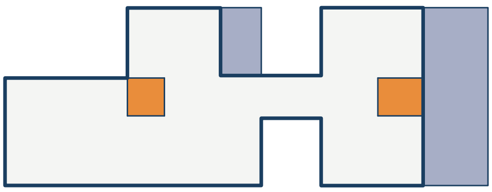
Third Floor

Open public spaces begin to **scatter**, allowing students to **spread out** during breaks. This **prevents congestion** and **fosters movement and engagement**.



Forth Floor

Public spaces continue to be scattered **across different areas**, **reducing overcrowding** and creating a **dynamic** school environment.



Fifth Floor

Different open spaces offer **flexibility** and enhance **social interaction** across floors. Emphasizing **openness**, **accessibility**, and **community engagement**.

Figure 6.11: Concept Diagrams, Elaborated by authors

6.2.2 Space Planning and Functional Zoning

The space planning and functional zoning for the **Yuan Ding Middle School extension** were developed based on a **list of functions derived from the school's official requests and documentation**. These documents provided essential guidelines for the required spaces and their intended use within the educational environment.

However, due to the **scope of the project** and the **primary design objectives**, not all requested functions were included in the final design. The selection and arrangement of spaces were guided by the **project's main goal**—to create an **efficient, flexible, and student-centered learning environment** while integrating seamlessly with the existing school infrastructure.

The final space allocation prioritizes **educational, social, and support functions**, ensuring a **balanced and functional layout** that meets both **immediate academic needs and long-term adaptability**.

Below is the **Functions Diagram**, illustrating the spatial distribution of different functions across the floors of the extension.

This diagram provides a clear visualization of how **educational, leisure, and support spaces** are organized throughout the building, ensuring **efficient circulation, accessibility, and usability**.

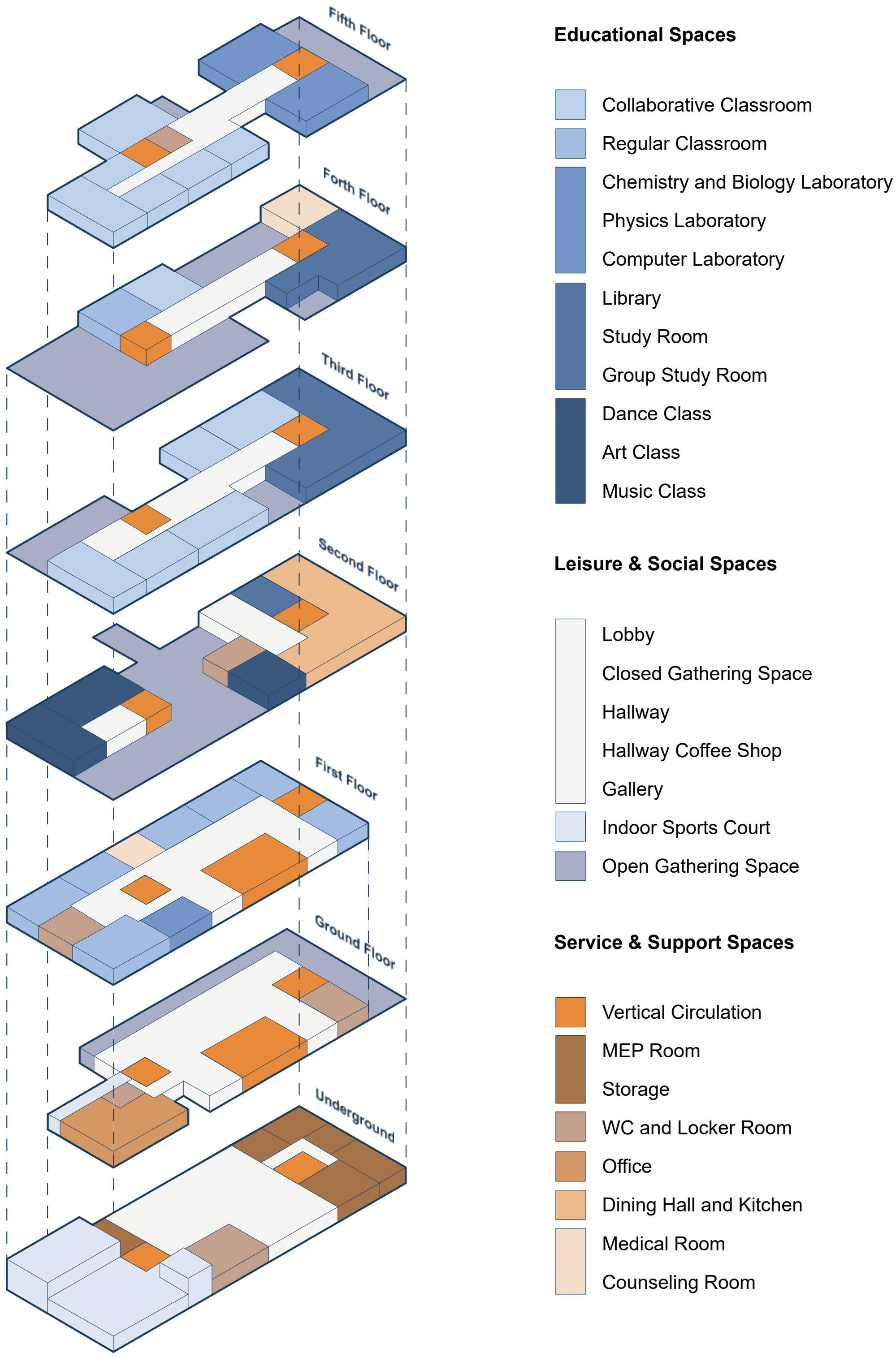


Figure 6.12: Floors Functions Diagram, Elaborated by authors

6.3 Project Documentation

6.3.1 Exterior Render

Figure 6.13: Exterior view of the project, Elaborated by authors

6.3.2 Site Plan

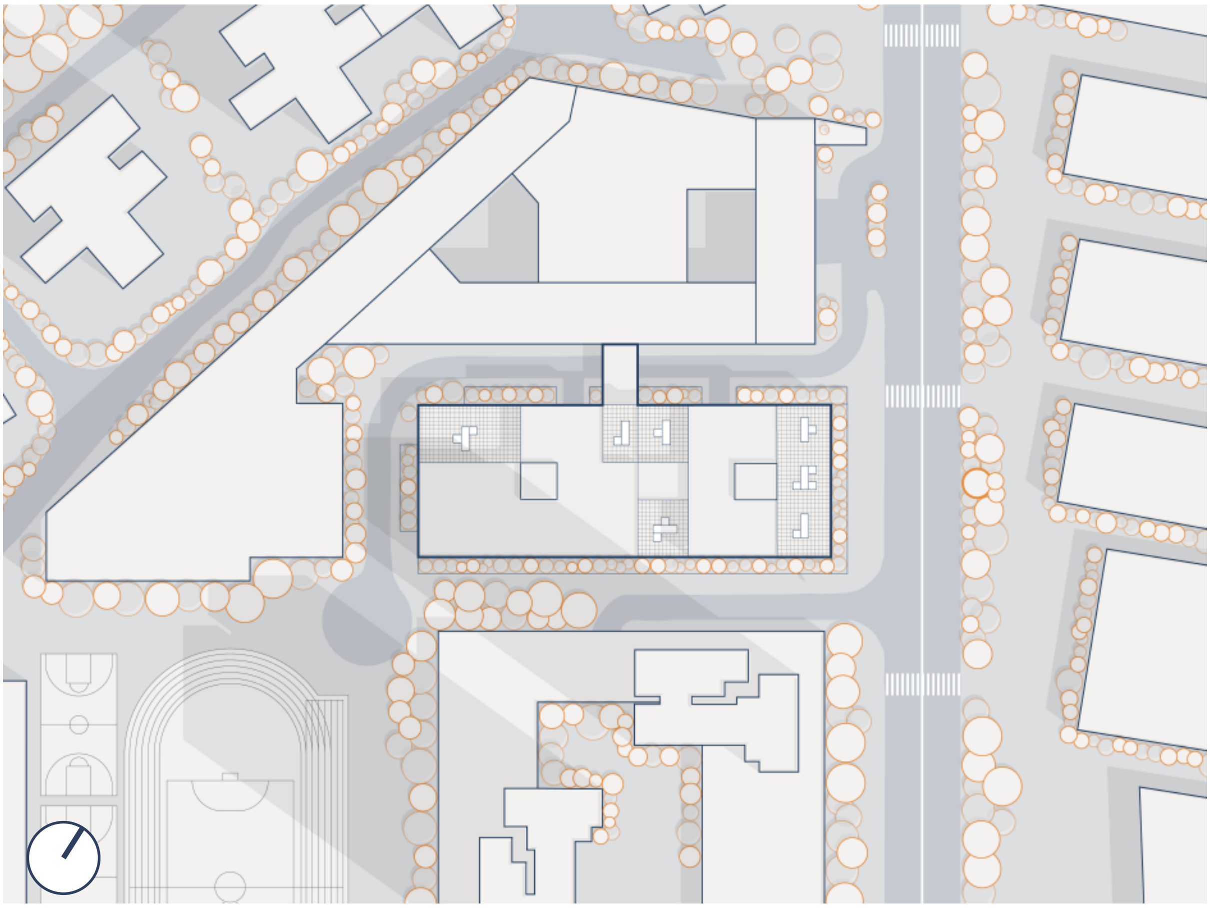


Figure 6.14: Site plan, Elaborated by authors

6.3.3 Axonometric View of the Building

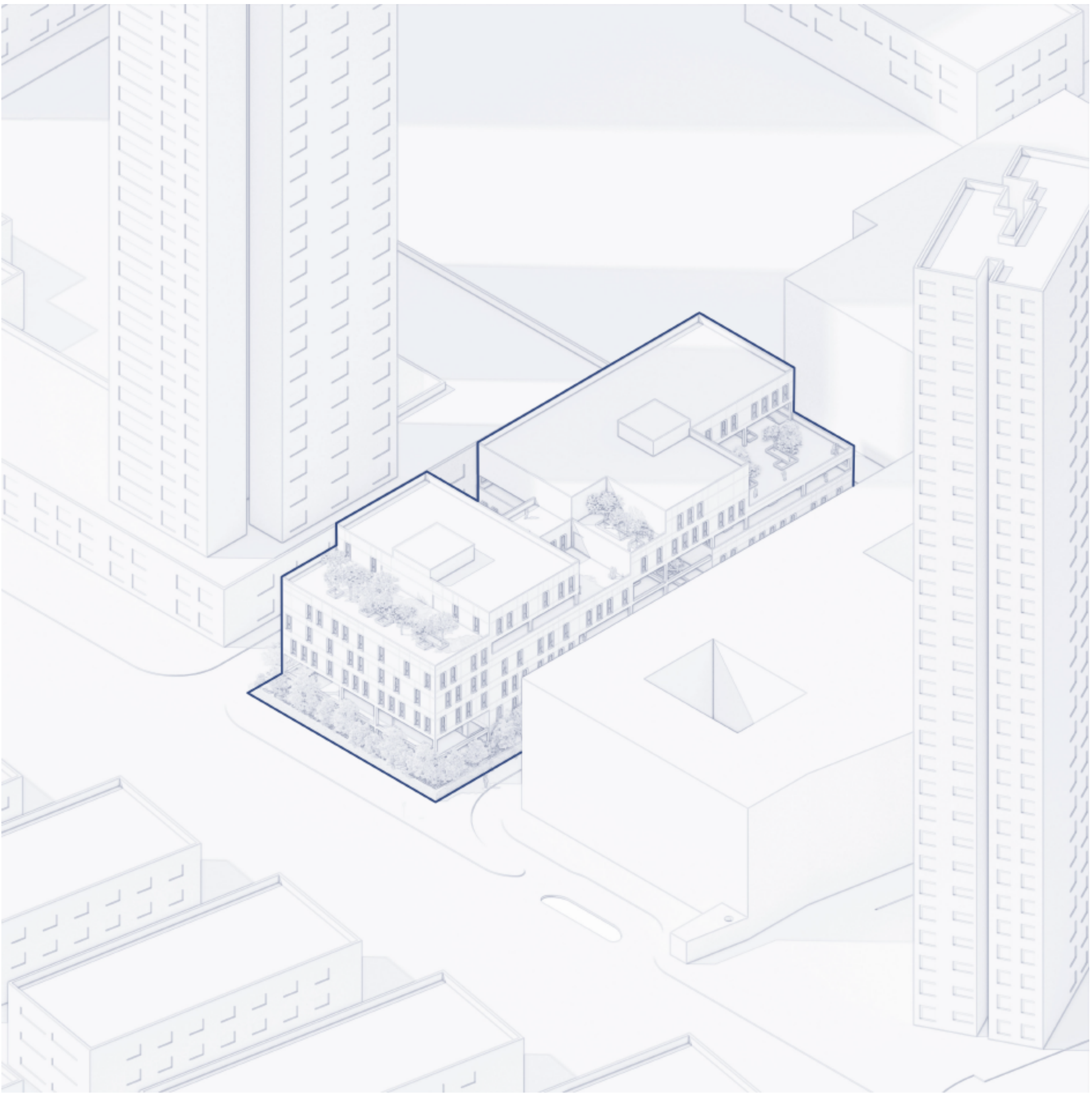


Figure 6.15: Axonometric view, Elaborated by authors

6.3.4 Axonometric View of the Building Structure

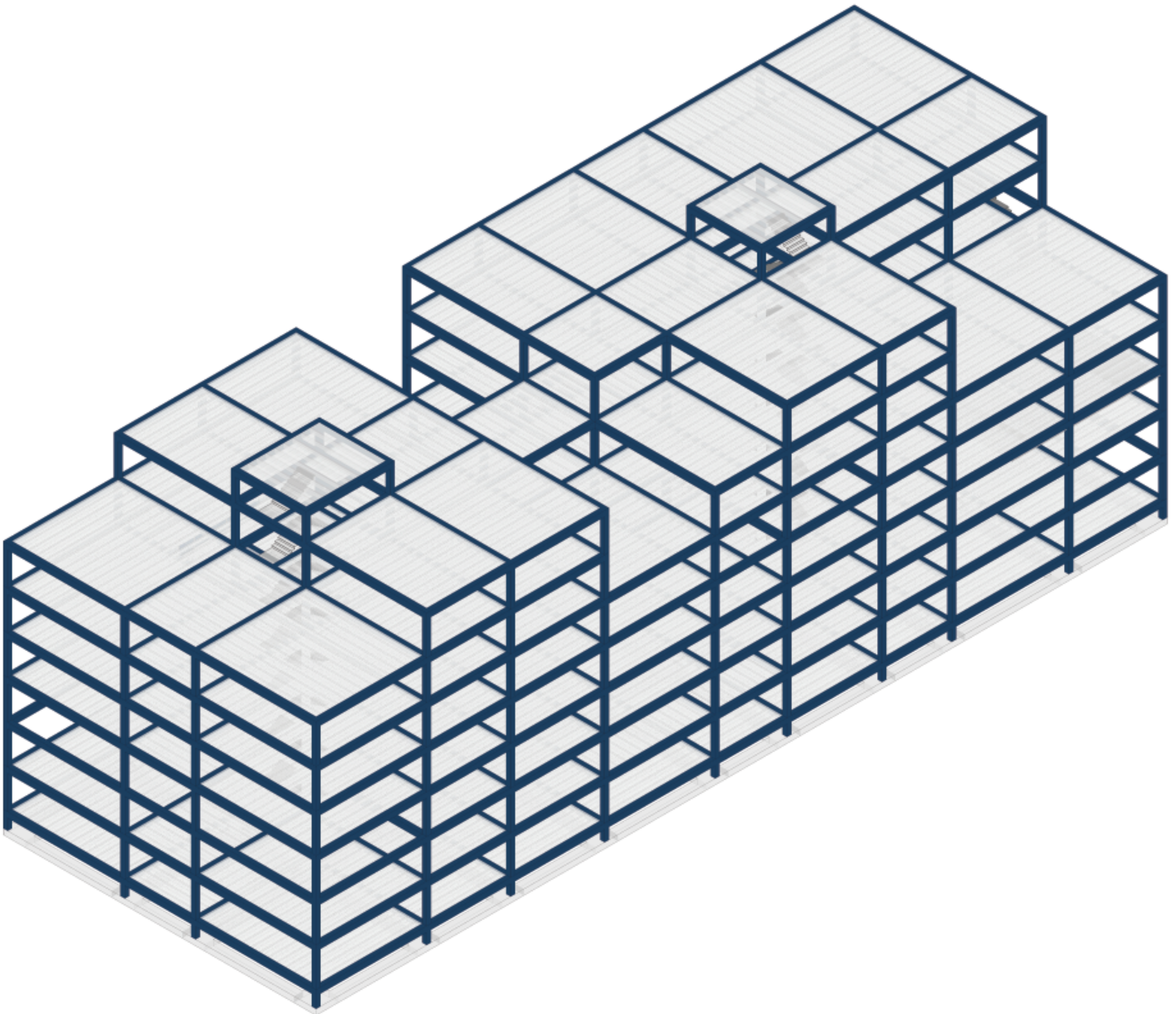


Figure 6.16: Structure Axonometric view, Elaborated by authors

6.3.5 Plans

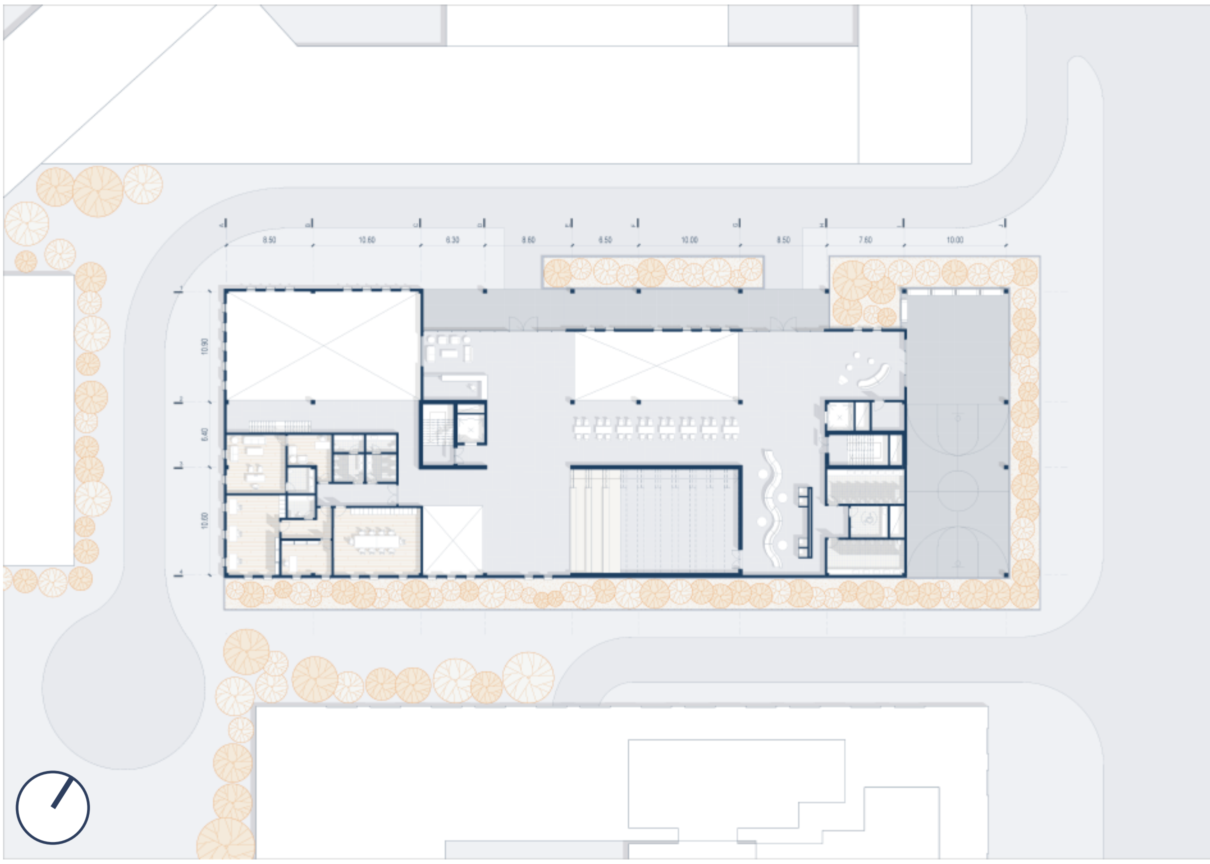


Figure 6.17: Ground Floor Plan, Elaborated by authors

Figure 6.18: First Floor Plan, Elaborated by authors

Figure 6.19: Second Floor Plan, Elaborated by authors

Figure 6.20: Third Floor Plan, Elaborated by authors

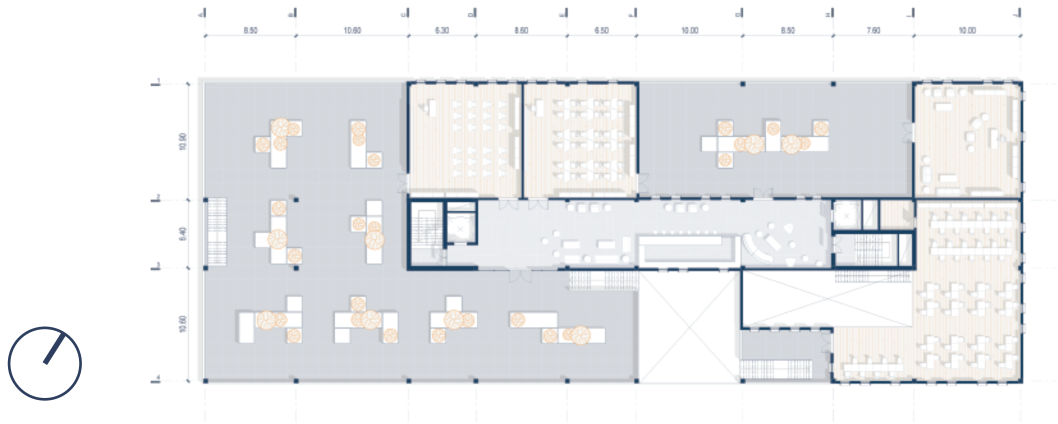


Figure 6.21: Forth Floor Plan, Elaborated by authors

Figure 6.22: Fifth Floor Plan, Elaborated by authors

Figure 6.22: Underground Plan, Elaborated by authors

6.3.6 Elevation

Figure 6.23: North Facade, Elaborated by authors

6.3.7 Section

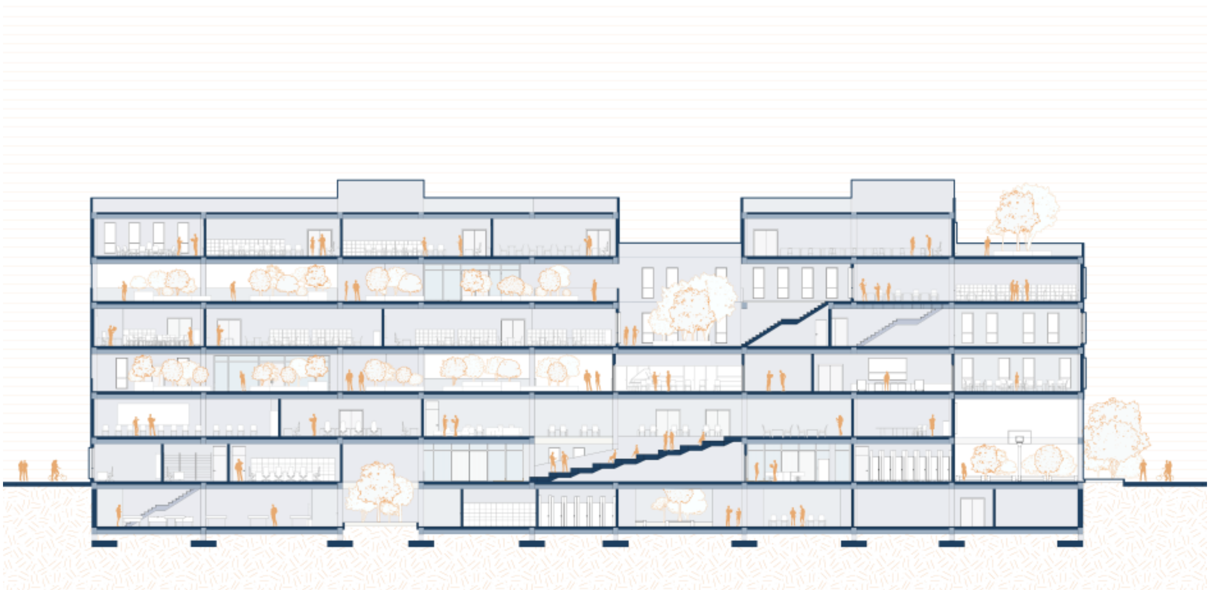


Figure 6.24: Section, Elaborated by authors

6.3.8 Detailed Classroom

In order to **demonstrate the level of detail, precision, and benefits of a high LOD (Level of Development) model**, we selected **one specific classroom** to develop up to **LOD 350**. This approach allows us to focus on **constructability, material specifications, and technical detailing**, ensuring that the **BIM model can be effectively used for fabrication and execution**.

Given the **scope and complexity of the overall project**, it was **not feasible to apply this level of detail to every classroom and space**. Instead, by choosing **one representative classroom**, we can effectively showcase the **process, methodology, and advantages of detailed BIM modeling**, without excessive time and resource investment.

This partial detailing provides valuable insights into how **BIM enhances design coordination, material specifications, and construction efficiency**. It also highlights the **potential cost savings, precision, and long-term benefits of an optimized BIM workflow**.The following sections present various aspects of the **detailed classroom**, including **axonometric views, renders, drywall and wall details, and cost analysis**.

6.3.8.1 Axonometric View

Figure 6.25: Axonometric view of the selected classroom, Elaborated by authors

6.3.8.2 Renders

Figure 6.26: Selected classroom View, Elaborated by authors

Figure 6.27: Selected classroom View, Elaborated by authors

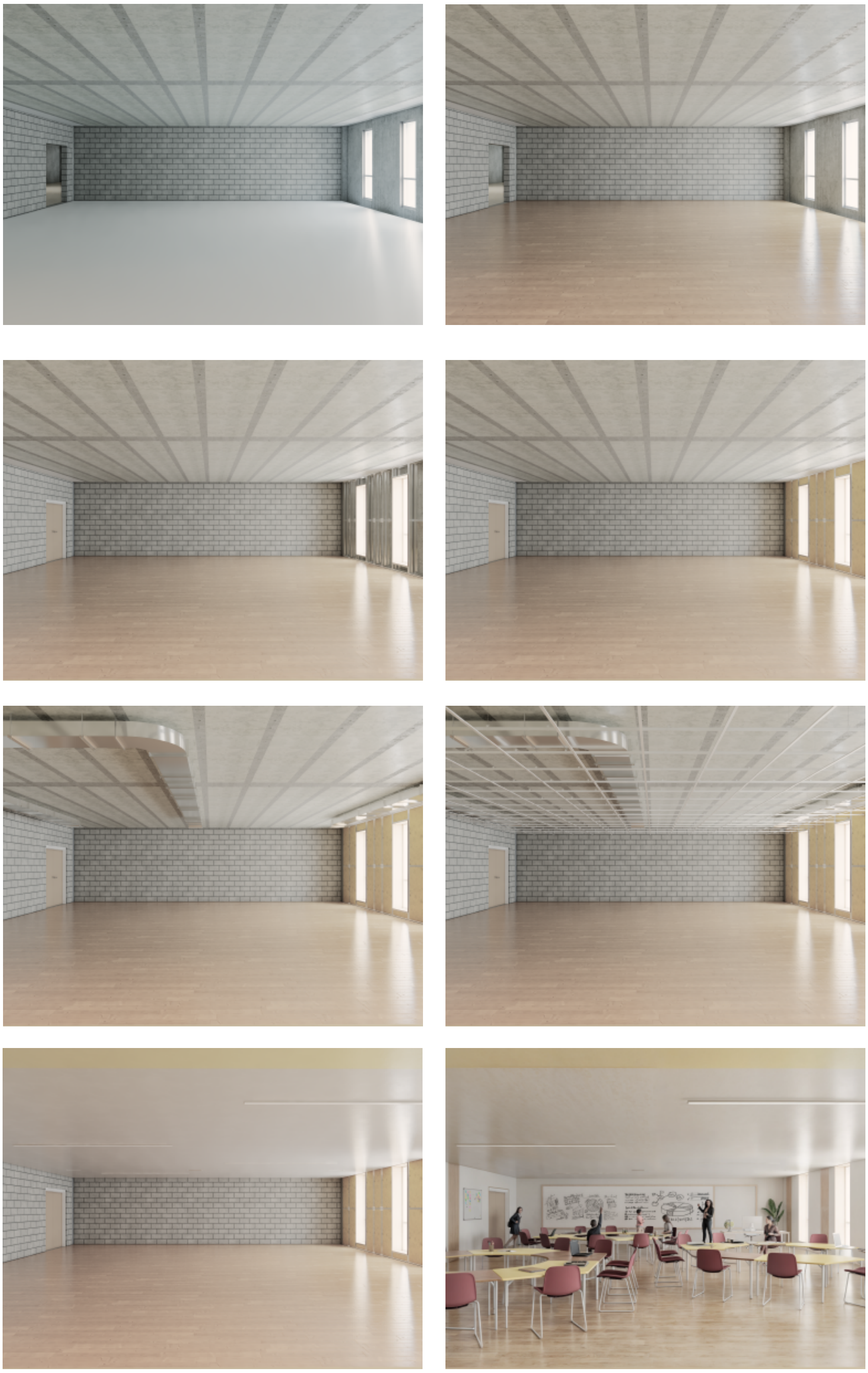


Figure 6.28: Selected classroom View Animation, Elaborated by authors

Animation Link:
https://drive.google.com/file/d/1K0Msz8Zyaq-P6vaVIPqRI1mIjZzTfUOu/view?usp=sharing

6.3.8.3 Drywall Detail

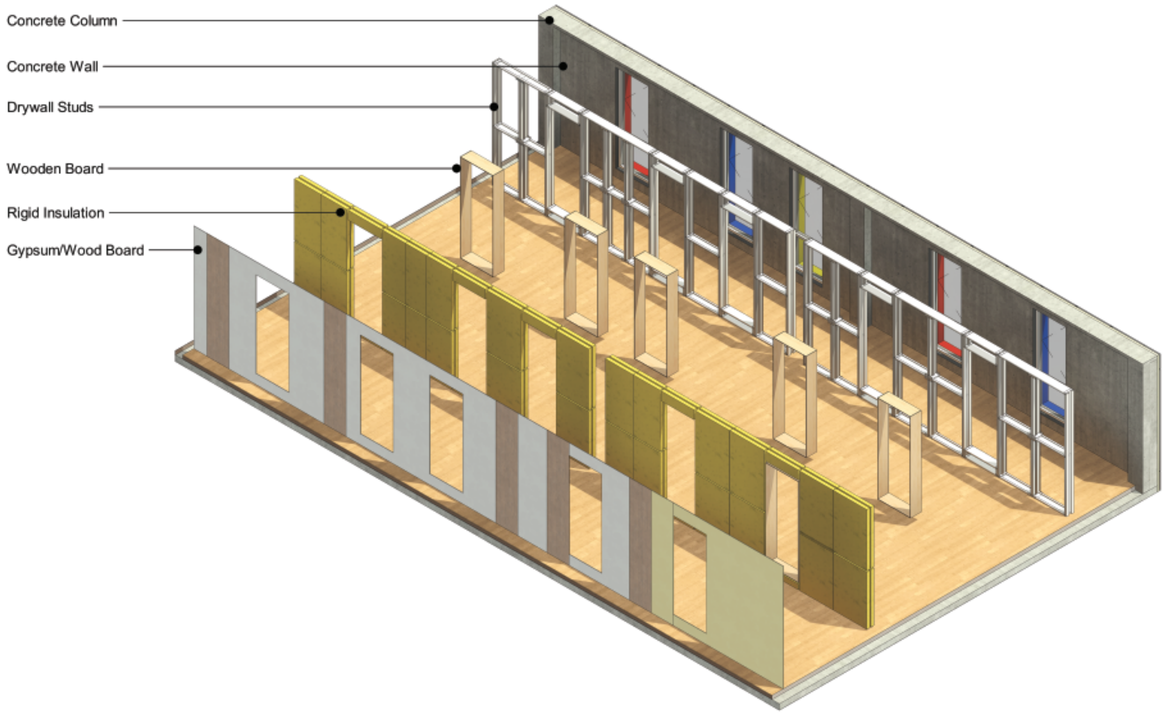


Figure 6.29: Selected classroom Drywall Detail, Elaborated by authors

6.3.8.4 Facade and Wall Detail

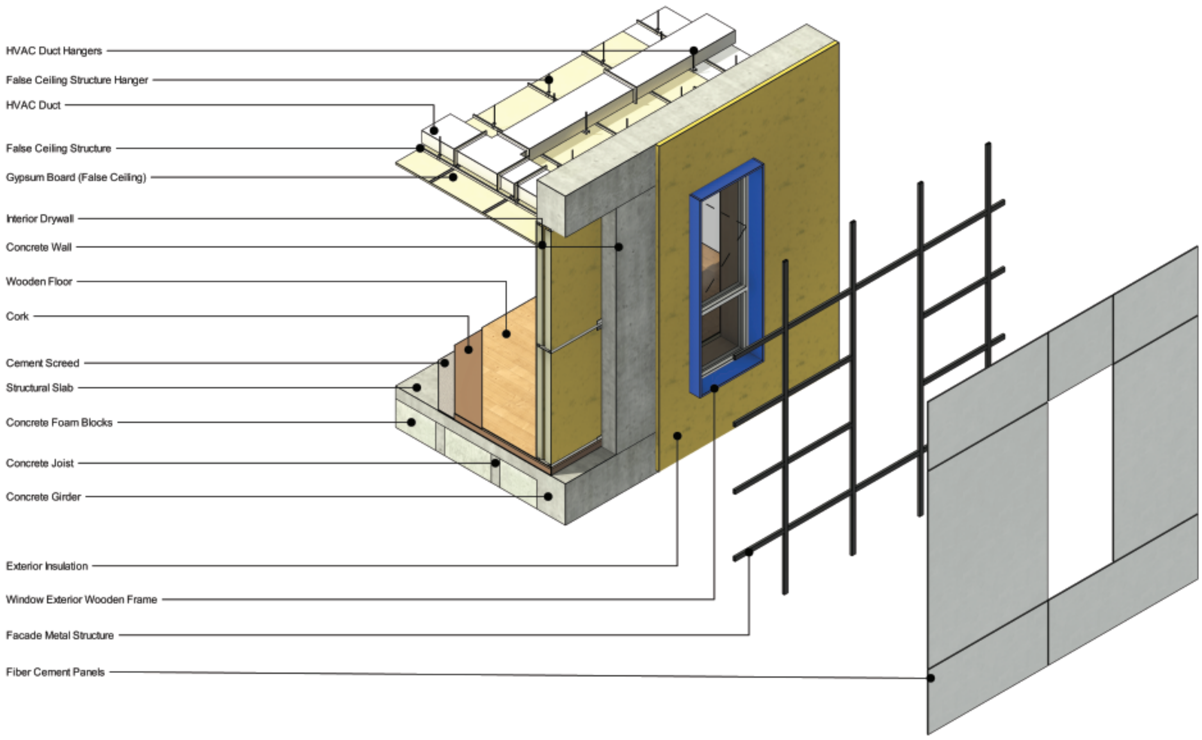


Figure 6.30: Selected classroom Wall and Facade Detail, Elaborated by authors

6.3.8.5 Cost Analysis

For this project, cost analysis was conducted specifically for the furniture within the selected classroom. This approach allows us to understand and quantify the material and financial implications of a single, detailed space, while also serving as a starting point for a broader 5D BIM analysis.

By analyzing the costs at a detailed level, we gain insights into budget allocation, material efficiency, and procurement planning. This process can later be expanded to other elements of the project, such as structural components, MEP systems, and finishes, forming a comprehensive 5D BIM model.

Why Focus on Classroom Furniture?

- **Scalability & Efficiency**: Analyzing the cost of furniture in one classroom provides a scalable methodology that can be applied across multiple spaces.
- **Material and Vendor Selection**: Understanding costs helps in choosing optimal materials and suppliers, ensuring budget efficiency.
- **BIM Integration**: Cost estimation through BIM models improves accuracy and efficiency, reducing errors in procurement and budgeting.

Towards a Full 5D BIM Approach

This partial cost analysis is an initial step toward implementing 5D BIM, where cost data is integrated directly into the digital model. A full 5D BIM model would enable:

- **Real-time cost tracking** as design changes occur.
- **Automated quantity take-offs**, reducing manual errors.
- **Budget forecasting** based on different design and material options.

Although a complete 5D BIM analysis was beyond the scope of this study, this cost breakdown of classroom furniture demonstrates the potential benefits of integrating financial data into the BIM workflow. It also provides a solid foundation for future cost analyses that could expand to cover the entire school extension.

Below is the cost analysis table detailing the estimated expenses for the selected classroom's furniture:

Yuan Ding School_Defined Classroom								
Furniture List and Cost								
Code	**Typology**	**Supplier**	**Specifications**	**Link**	**Reference Picture**	**Quantity**	**Unit Cost**	**Total Cost**
F1	Student's Chair	Inspec Furniture	Color Dark Red Size 78*45*53	Link		36	€1,140.00	€41,040.00
F2_A	Student's Table (Wooden)	Furnitureforschools	Color Wood Material Size 180*180*60	Link		9	€216.00	€1,944.00
F2_B	Student's Table (Colored)	Furnitureforschools	Color Yellow Size 180*180*60	Link		9	€216.00	€1,944.00
F3	Teacher's Chair	Inspec Furniture	Color White Size 66*66*100	Link		1	€2,600.00	€2,600.00
F4	Teacher's Table	Watson	Color White Size 30*84*42	Link		1	€1,200.00	€1,200.00
F6	Pouf	Lammhults	Color Red Size 80*75*42	Link		7	€350.00	€2,450.00
F7	Pouf	AJ Products	Color Light Grey Size 45*45*47	Link		4	€225.00	€900.00
								€52,078.00

Table 6.1: Selected Classroom Furnitures List and Cost, Total Cost, Elaborated by authors

6.4 Construction Management

6.4.1 Shared Coordinates for Team Collaboration

To ensure seamless collaboration among disciplines, shared coordinates are typically utilized to establish a unified reference system. This method enables multiple stakeholders—architects, engineers, and contractors—to work on their respective aspects of the project while maintaining alignment in spatial data. Shared coordinates are instrumental in mitigating potential issues such as misalignments between structural and architectural elements, reducing errors during later project phases.

However, due to certain limitations in this study, such as software access constraints and the scope of the case study as a student project, we were unable to fully implement shared coordinates for the Yuan Ding Middle School extension. While this aspect remains a theoretical consideration in our proposed workflow, it underscores the importance of this practice in professional BIM workflows. Future applications of the workflow with full access to the required tools could demonstrate the significant benefits of shared coordinates in achieving seamless interdisciplinary collaboration.

6.4.2 Work Breakdown Structure (WBS): Phased Task Organization

The project was divided into manageable phases using a Work Breakdown Structure (WBS). This hierarchical framework categorized tasks by discipline, priority, and project stage, ensuring clear allocation of responsibilities. The phased approach allowed for detailed tracking of progress, resource allocation, and potential workflow inefficiencies, enabling a more organized and efficient process.

Code	Category	Task	Start	End	Duration
1.0.1	Site Preparation	Earthworks	2025-02-03	2025-02-13	10
1.0.2	Site Preparation	Excavation	2025-02-14	2025-02-21	7
1.0.3	Site Preparation	Foundation Slab	2025-02-22	2025-03-04	10
1.0.4	Site Preparation	Foundation Framing	2025-03-05	2025-03-12	7
1.0.5	Site Preparation	Foundation Columns	2025-03-13	2025-03-20	7
2.0.1	Structural Work	Floor 1 Beams	2025-03-21	2025-03-24	3
2.0.2	Structural Work	Floor 1 Joists	2025-03-25	2025-03-28	3
2.0.3	Structural Work	Floor 1 Foam	2025-03-29	2025-04-01	3
2.0.4	Structural Work	Floor 1 Floor	2025-04-02	2025-04-05	3
2.0.5	Structural Work	Floor 1 Columns	2025-04-06	2025-04-09	3
2.0.6	Structural Work	Floor 2 Beams	2025-04-10	2025-04-13	3
2.0.7	Structural Work	Floor 2 Joists	2025-04-14	2025-04-17	3
2.0.8	Structural Work	Floor 2 Foam	2025-04-18	2025-04-21	3
2.0.9	Structural Work	Floor 2 Floor	2025-04-22	2025-04-25	3
2.0.10	Structural Work	Floor 2 Columns	2025-04-26	2025-04-29	3
2.0.11	Structural Work	Floor 3 Beams	2025-04-30	2025-05-03	3
2.0.12	Structural Work	Floor 3 Joists	2025-05-04	2025-05-07	3
2.0.13	Structural Work	Floor 3 Foam	2025-05-08	2025-05-11	3
2.0.14	Structural Work	Floor 3 Floor	2025-05-12	2025-05-15	3
2.0.15	Structural Work	Floor 3 Columns	2025-05-16	2025-05-19	3
2.0.16	Structural Work	Floor 4 Beams	2025-05-20	2025-05-23	3
2.0.17	Structural Work	Floor 4 Joists	2025-05-24	2025-05-27	3
2.0.18	Structural Work	Floor 4 Foam	2025-05-28	2025-05-31	3
2.0.19	Structural Work	Floor 4 Floor	2025-06-01	2025-06-04	3
2.0.20	Structural Work	Floor 4 Columns	2025-06-05	2025-06-08	3
2.0.21	Structural Work	Floor 5 Beams	2025-06-09	2025-06-12	3
2.0.22	Structural Work	Floor 5 Joists	2025-06-13	2025-06-16	3
2.0.23	Structural Work	Floor 5 Foam	2025-06-17	2025-06-20	3
2.0.24	Structural Work	Floor 5 Floor	2025-06-21	2025-06-24	3
2.0.25	Structural Work	Floor 5 Columns	2025-06-25	2025-06-28	3
2.0.26	Structural Work	Floor 6 Beams	2025-06-29	2025-07-02	3
2.0.27	Structural Work	Floor 6 Joists	2025-07-03	2025-07-06	3
2.0.28	Structural Work	Floor 6 Foam	2025-07-07	2025-07-10	3
2.0.29	Structural Work	Floor 6 Floor	2025-07-11	2025-07-14	3
2.0.30	Structural Work	Floor 6 Columns	2025-07-15	2025-07-18	3

Table 6.2: Work Breakdown Structure, Elaborated by authors

6.4.3 Interoperability Among Software: Rhino, Revit, and Navisworks

The integration of Rhino, Revit, and Navisworks demonstrated the importance of interoperability in modern construction workflows. Rhino facilitated early-stage conceptual design, while Revit enabled detailed modeling and documentation. Navisworks was utilized for clash detection and 4d time analysis and construction simulation. The ability to transfer data seamlessly between these platforms minimized redundancies and ensured consistency in design and construction processes.

6.4.4 4D Analysis: Time Simulation Using Navisworks

The 4D simulation conducted in Autodesk Navisworks integrated construction scheduling (Work Breakdown Structure - WBS) with the 3D BIM model, providing a real-time, dynamic visualization of the construction sequence over time. This simulation enabled the project team to better anticipate scheduling conflicts, optimize workflows, and enhance resource planning, ultimately improving overall project efficiency.

Link to 4d analysis animation:

https://drive.google.com/file/d/1xtxhmpbMbJiQHrMNLOCgK7Xf-TbpUTP5/view?usp=sharing

Key Benefits of the 4D Simulation:

Visualizing Construction Phases

The animation provided a **step-by-step visual representation** of how different building elements are constructed over time.

This helped in **understanding dependencies between construction activities**, ensuring that tasks followed a **logical, sequential order**.

Conflict Detection & Risk Mitigation

By simulating the **timeline of the construction process**, potential scheduling **clashes and site coordination issues** could be identified early.

This allowed the team to **proactively adjust schedules**, reducing **unexpected delays and on-site disruptions**.

Workflow Optimization & Resource Allocation

The **4D BIM model linked project activities with real-time scheduling**, helping **optimize labor, material deliveries, and equipment use**.

Efficient sequencing ensured that **construction teams could work without interruptions**, improving productivity and reducing downtime.

Improved Communication & Stakeholder Engagement

The animation served as a **powerful communication tool**, making construction planning more **transparent and understandable** for all stakeholders.

This was particularly useful for **non-technical stakeholders**, such as **clients, investors, and school administrators**, allowing them to **visualize progress intuitively**.

Scenario Testing & Decision-Making

Different **construction scenarios** could be tested in Navisworks, allowing for **alternative sequencing strategies**.

This flexibility enabled the team to **adapt to real-world constraints**, such as **weather conditions, supply chain delays, or labor availability**.

Conclusion

The **4D analysis in Navisworks** demonstrated how **time-based BIM simulations** can significantly improve **construction planning, coordination, and efficiency**. While this simulation was focused on the **school extension**, the methodology can be scaled for **larger and more complex projects**, reinforcing the **value of integrating BIM with scheduling workflows**.

6.4.5 5D Analysis: Cost Estimation

The incorporation of cost data into the BIM model enabled the creation of a 5D simulation in Navisworks, allowing for real-time cost estimation and budget tracking throughout the project lifecycle. This approach enhances financial planning and cost control, ensuring that design decisions align with budget constraints.

One of the primary benefits of 5D BIM is the ability to automate quantity take-offs, reducing manual errors and improving accuracy. Additionally, by linking cost data to design components, the project team can visualize financial impacts dynamically, making informed decisions about material selection and resource allocation.

Starting 5D BIM with Classroom Furniture Cost Analysis

In this study, we conducted a cost analysis for the furniture of a selected classroom, serving as an initial step toward a full 5D BIM workflow. This focused approach allows us to demonstrate the integration of cost data within BIM, highlighting its potential for budget estimation and financial tracking.

- The classroom furniture cost study illustrates how individual elements can be linked to pricing, forming the basis for future cost modeling.
- This partial 5D analysis showcases how financial data can be embedded into the BIM model, paving the way for a more detailed, scalable cost estimation process.

Limitations & Future Scope

Due to the scope of the student project, the 5D cost analysis was conducted only for classroom furniture rather than the entire construction project. However, this demonstrates the process and potential of BIM-based cost analysis, showing how future expansions could include structural, material, and labor costs to develop a comprehensive 5D BIM model.

This study serves as a foundation for integrating cost estimation with BIM workflows, illustrating how financial tracking can be streamlined in real-world applications. Future research can build upon this initial work to expand cost modeling across the full construction process, leveraging 5D BIM for enhanced financial oversight and decision-making.

Chapter 7

7. Conclusion

The conclusion of this thesis serves as a critical bridge between the theoretical discussions on Building Information Modeling (BIM) and its practical applications, as demonstrated in the case study of the Yuan Ding Middle School extension. The research first explored the foundational principles of BIM, including its ability to enhance collaboration, streamline project workflows, and mitigate inefficiencies in traditional Architecture, Engineering, and Construction (AEC) processes. These theoretical insights were then partially tested in a real-world-inspired scenario, where the capabilities of BIM were evaluated against conventional CAD-based workflows.

By integrating these two components—theoretical exploration and practical application—this thesis demonstrates how abstract concepts of BIM can be translated into concrete, actionable workflows. The research highlights how BIM-based methodologies address key collaboration challenges, such as fragmented communication, information silos, and manual inefficiencies, which are common in traditional AEC project delivery. The case study and workflow simulation provide empirical support for BIM's transformative potential, showcasing its ability to facilitate real-time collaboration, automate design modifications, and improve coordination among multidisciplinary teams.

Moreover, the findings of this thesis emphasize the importance of a structured approach to BIM implementation. While BIM offers significant advantages over traditional CAD workflows, its successful adoption requires proper training, software access, and a well-defined collaboration strategy. The analysis presented in this thesis not only validates BIM's effectiveness but also sheds light on the challenges that organizations must navigate when transitioning from traditional methodologies to an integrated BIM approach.

In essence, this thesis reinforces the notion that BIM is more than just a software tool—it is a paradigm shift in the way AEC professionals approach project design, coordination, and execution. Through the case study and comparative analysis, the research provides a comprehensive framework for understanding how BIM can optimize collaboration in real-world projects, offering valuable insights for both academia and industry stakeholders.

7.1 Recap of Theoretical Insights

The theoretical foundation of this thesis explored the critical challenges and opportunities within the Architecture, Engineering, and Construction (AEC) industry, particularly in relation to collaboration and workflow efficiency. These discussions established the need for a more integrated, technology-driven approach to project execution, leading to an in-depth analysis of Building Information Modeling (BIM) as a transformative tool. The key theoretical insights covered in this thesis are as follows:

7.1.1 The Limitations of Traditional CAD Workflows

Traditional Computer-Aided Design (CAD) workflows rely heavily on 2D drafting, with separate, fragmented documentation that lacks dynamic connectivity between different project components. This siloed approach leads to several inefficiencies:

- **Error Propagation**: Since design changes must be manually updated across multiple drawings, inconsistencies often arise, leading to misalignment between project phases.
- **Lack of Real-Time Collaboration**: Stakeholders work on separate files, which can result in version control issues and communication gaps.
- **Time-Consuming Revisions**: Coordinating changes across different teams is slow and labor-intensive, increasing project timelines and costs.
- **Limited Data Integration**: CAD models primarily focus on geometric representation rather than integrating critical information such as materials, costs, and scheduling.

7.1.2 BIM's Transformative Potential

BIM emerged as a solution to overcome the inefficiencies of traditional workflows by providing an intelligent, centralized, and data-driven approach to design and project management. The key advantages of BIM include:

- **Integrated Model-Based Design**: Unlike CAD, BIM centralizes project data, ensuring that changes are reflected across all associated plans, sections, and 3D models in real time.
- **Automated Workflow and Clash Detection**: BIM tools, such as Revit and Navisworks, enable automatic updates and clash detection, reducing coordination errors and the need for rework.

- **Interdisciplinary Collaboration**: BIM allows multiple stakeholders—architects, structural engineers, mechanical engineers, and contractors—to work on a shared model, ensuring better alignment and reducing redundancy.
- **Advanced Analytical Capabilities**: BIM extends beyond 3D modeling by incorporating 4D (time), 5D (cost), 6D (sustainability), and 7D (facility management) dimensions, providing deeper insights into project planning and execution.

7.1.3 Collaboration Challenges in the AEC Industry

One of the core issues in AEC project management is the difficulty of fostering seamless collaboration among diverse teams. The research identified several barriers:

- **Siloed Workflows**: In traditional methods, each discipline operates independently, leading to delays in information exchange and coordination issues.
- **Ineffective Communication**: The use of disconnected tools and platforms often results in miscommunication, affecting project efficiency and decision-making.
- **Version Control Issues**: Without a unified data environment, stakeholders may work with outdated or conflicting design files, leading to inconsistencies.
- **Fragmented Project Management**: Conventional workflows do not provide real-time updates, making it difficult to track project progress and respond to changes efficiently.

BIM has been identified as a key enabler of improved collaboration by offering real-time model updates, cloud-based data sharing, and enhanced interoperability among different disciplines. By addressing the fragmentation of traditional workflows, BIM fosters a more integrated and coordinated approach to project delivery.

These theoretical insights provided a strong foundation for the practical exploration of BIM in the case study of the Yuan Ding Middle School extension. The subsequent analysis aimed to validate the benefits of BIM-based collaboration while also identifying potential challenges and areas for improvement in its implementation.

7.2 Key Learnings Applied in the Case Study

The case study of the **Yuan Ding Middle School extension** provided an opportunity to **partially test and validate** the theoretical insights discussed earlier. By applying BIM-based methodologies in a real-world-inspired project, the study examined its impact on interdisciplinary collaboration, workflow efficiency, and advanced analytical capabilities. The key findings from this practical application are as follows:

- Interdisciplinary Collaboration Using BIM: Revit's collaboration tools enabled simultaneous work on architectural and mechanical systems. The use of shared worksets ensured alignment and reduced redundant efforts.

- Workflow Efficiency: The simulation compared BIM and CAD workflows, demonstrating how BIM's integrated model eliminates the need for repetitive manual updates. This practical application validated BIM's efficiency advantages outlined in the theoretical section.

- 4D and 5D Capabilities: Although partially implemented, the ability to simulate construction sequencing (4D) and perform preliminary cost analysis (5D) demonstrated the advanced functionality of BIM tools.

Key Area	Findings	Challenges
Interdisciplinary Collaboration	Improved alignment between disciplines, reduced redundancy, and enhanced real-time coordination through shared BIM models.	Learning curve for users, software access limitations, and challenges in setting up shared coordinates.
Workflow Efficiency	BIM's automation eliminated repetitive manual work, improved accuracy, and enabled faster design iterations.	Hardware/software limitations and need for structured training programs.
4D and 5D Capabilities	Demonstrated the potential of construction sequencing (4D) and cost analysis (5D) for better project management.	Partial implementation due to resource constraints, requiring further exploration for full integration.

Table 7.1: Summary of Key Learnings, Elaborated by authors

These findings reinforce BIM's role as a transformative tool in AEC collaboration and workflow optimization. While the case study validated many theoretical advantages, it also highlighted practical barriers that must be addressed to ensure successful BIM adoption on a broader scale.

7.3 Case Study Reflections Informing Theory

The case study of the Yuan Ding Middle School extension not only served as a validation of BIM's theoretical benefits but also provided critical feedback on the practical challenges of implementation. These reflections help refine the theoretical framework, highlighting both the opportunities and obstacles encountered when transitioning from traditional CAD-based workflows to BIM-driven methodologies.

1. Validation of BIM Advantages: The findings from the case study reinforced BIM's transformative role in reducing errors, improving collaboration, and streamlining workflows, aligning with the theoretical discussions presented earlier

2. Highlighting Practical Challenges: The learning curve associated with BIM tools was a significant factor, requiring additional time and resources for proficiency. Resource constraints, such as limited access to advanced software and collaboration platforms, impacted the full realization of BIM's potential.

3. Emerging Insights: The simulation raised questions about how to better train teams for seamless adoption of BIM workflows. The importance of early coordination and shared coordinates to avoid misalignments became evident.

7.4 Results and Reflections

Outcomes of the School Extension Design

The Yuan Ding Middle School extension project successfully achieved several key objectives, including the development of a comprehensive BIM model that integrates architectural, structural, and functional elements. The design process emphasized modularity, adaptability, and sustainability, providing a detailed proposal that aligns with the educational needs of a growing student population. Despite certain limitations, the project showcased the capacity of BIM to create detailed models that support advanced simulations, such as 4D scheduling and partial 5D cost analysis. The proposed extension includes well-zoned spaces for academic, administrative, and recreational purposes, fostering an efficient and engaging learning environment.

7.5 Lessons Learned from the BIM Workflow

Lessons Learned	Description
Interdisciplinary Collaboration	BIM demonstrated its potential to facilitate interdisciplinary coordination. However, the lack of shared coordinates highlighted the need for early alignment among project stakeholders.
Real-Time Updates	The capability of BIM to update and share information in real-time proved invaluable for maintaining data consistency across project stages.
Partial Adoption	While the 4D and 5D analyses provided insights into time and cost implications, their partial implementation revealed the importance of having complete access to tools and resources to fully utilize BIM's potential.
Software Interoperability	The integration of tools like Revit and Navisworks illustrated the advantages of interoperability in managing complex workflows, despite challenges stemming from software limitations and learning curves.

7.6 Evaluating the Strengths, Weaknesses, Opportunities, and Threats of the Proposed Workflow (SWOT Analysis)

Figure 7.1: SWOT Analysis of BIM VS CAD Workflow, Elaborated by authors

7.7 Future Applications and Recommendations

Future Applications	Description
Full Integration of Advanced BIM Dimensions	Future projects should strive for **complete implementation of 4D and 5D BIM**, enabling enhanced **construction sequencing (4D)** and **cost estimation (5D)**. Organizations must invest in **adequate resources, software, and training** to fully utilize these advanced BIM functionalities.
Enhanced Interdisciplinary Collaboration	A key takeaway from the case study was the **importance of seamless collaboration** between different disciplines. Implementing **shared coordinates** and a **Common Data Environment (CDE)** will enhance real-time updates and ensure **data consistency** among architects, engineers, and contractors.
Standardized Workflows and Training	BIM adoption faces challenges due to **inconsistent standards and varying expertise levels**. Establishing **clear BIM protocols**, alongside **structured training**, will **reduce the learning curve** and **streamline project execution**. Professional firms should incorporate **progressive BIM learning strategies** into their training.
Technology Accessibility	Ensuring **wider access** to comprehensive software suites and compatibility between tools will streamline workflows.
Sustainability Integration	Extending BIM into **6D and 7D** will improve **environmental performance** and ensure **long-term operational efficiency**. The integration of **energy analysis, lifecycle costing, and maintenance** will allow for more **sustainable and cost-effective building management**.

Table 7.2: Future Applications and Recommendations, Elaborated by authors

7.8 Broader Implications for BIM in Education Facility Design

The integration of BIM-based methodologies in the design, construction, and management of educational facilities holds significant long-term benefits. Schools, universities, and other academic institutions require highly adaptable spaces that evolve with pedagogical advancements, technological innovations, and changing student populations. BIM provides a data-driven, collaborative approach that can optimize facility planning, streamline construction processes, and enhance long-term operational efficiency.

Broader Implications for BIM	**Description**
Enhanced Learning Environments	BIM allows for the design of dynamic and adaptable learning spaces, ensuring that educational facilities can evolve with changing teaching methods and curriculum demands. Advanced visualization tools -like VR- help educators and administrators actively participate in the design process, ensuring that learning environments are student-centric and functional.
Efficiency Gains	The integration of 4D scheduling and 5D cost estimation within BIM ensures that construction delays and budget overruns are minimized.
Improved Stakeholder Collaboration	BIM fosters alignment between educators, architects, and contractors.
Lifecycle Management	By incorporating 6D and 7D BIM, long-term operational costs can be reduced while ensuring sustainability.

Table 7.3: Broader Implications for BIM in Education Facility Design, Elaborated by authors

Chapter 8

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