Extended Reality and BIM 4D For Enhancing Visualization, Logistics, and Workflow Efficiency:
An Application in the Mountain Environment

Politecnico di Torino | DAD - Master's Thesis
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"so i just found out that apparently, a lemon isn't naturally occurring and is a hybrid by cross breeding a bitter orange and a citron, which means life never gave us lemons; we invented them all by ourselves"
-unknown source

Abstract

As the fourth industrial revolution advances, industries are increasingly integrating technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) to enhance traditional workflows. These technologies increase efficiency and reduce risk by enabling the early identification and resolution of potential issues.

This thesis questions traditional construction management approaches and addresses the logistical and operational challenges of constructing a modular house in the mountainous terrain where access is limited to footpaths and standard vehicles cannot operate. The study focuses on overcoming logistical and operational barriers, including the transportation of tools and materials, the acceleration of construction timelines, and the reduction of risks in such a challenging environment. The research examines the applications, capabilities, limitations, and potential of VR, AR, and MR technologies in construction management. as part of the case study, a field survey was conducted to capture the current situation with point cloud data. BIM tools were used to model construction phases, simulate workflows, and optimize logistics through Gantt chart. At last, a MR application was developed to visualize construction phases and support on-site decision making.

The results highlight how MR technology clearly enhances construction planning and execution in remote locations by lowering logistical errors, minimizing errors, and improving time management. This thesis provides a framework for leveraging mixed reality solutions to address the unique challenges of construction in difficult-to-access environments, contributing to the advancement of technology-driven construction management.

Acknowledgement

To tutors, specifically to Nicola for his guidance and his help throughout the whole process, even with 9698 km distance and 8 hours of difference. Nicola has consistently been there for me when I needed assistance and guidance. He consistently ensured the availability of the lab's necessary tools.

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"Last but not least, I want to thank me for believing in me, for doing all this hard work..."

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Acronyms:

- AEC – Architecture, Engineering, and Construction
- AI – Artificial Intelligence
- API – Application Programming Interface
- AR – Augmented Reality
- BIM – Building Information Modeling
- CAD – Computer-Aided Design
- CBS – Cost Breakdown Structure
- CMS – Content Management System
- CSV – Comma-Separated Values
- FOV – Field of View
- GIS – Geographic Information System
- HMD – Head-Mounted Display
- IMPP – Microsoft Project File Format
- LiDAR – Light Detection and Ranging
- MR – Mixed Reality
- NLP – Natural Language Processing
- NWD – Navisworks Document File
- NWF – Navisworks Working File
- NWC – Navisworks Cache File
- OBS – Organization Breakdown Structure
- SLAM – Simultaneous Localization and Mapping
- VR – Virtual Reality
- WBS – Work Breakdown Structure
- XR – Extended Reality

File Formats:

- CSV – Comma-Separated Values
- DWG – AutoCAD Drawing File Format
- IMPP – Microsoft Project File Format
- NWC – Navisworks Cache File
- NWD – Navisworks Document File format)
- NWF – Navisworks Working File
- RCP – ReCap Point Cloud File
- RCS – ReCap Scan File
- XYZ – ASCII point cloud format

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1. Introduction

At this very moment, the construction industry is going through a technological transformation that is actually quite significant. Through the incorporation of digital tools and immersive technologies into the processes that are currently accepted for projects, it is possible to make this change more accessible. It is becoming increasingly clear that the value of Extending Reality (XR), which encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), are being demonstrated in terms of improving vision, decision-making, and building management (Pan, N., & Isnaeni, N. N., 2024). This comes from ever challenging sustainability issues and ever complicated construction projects. Concurrently, Building Information Modeling (BIM 4D) is altering project coordination by letting the evolution of digital representations of building phases, sequencing, and scheduling. XR and BIM have made tremendous development, but their actual use in practical building management is still lacking enough studies.

This thesis examines the incorporation of XR and BIM 4D in a modular prefabricated building project, emphasizing workflow efficiency, logistics optimization, and visualization enhancement. Piedicavallo, Italy, serves as an exemplary test case for prefabrication and XR-driven project coordination due to its remote mountainous location, challenging terrain, and restricted accessibility. This study aims to show how XR and BIM 4D could be able to remove logistical obstacles, reduce mistakes, and increase project efficiency on challenging access to construction sites. This will be achieved by looking at methodical integration of these two technologies.

1.1 Research Question

This paper seeks to clarify how Extended Reality (XR) technologies might enhance construction management in settings either geographically far-off or logistically difficult. The study's main concern is as follows:

How can the integration of BIM 4D and XR technologies enhance workflow efficiency, optimize logistics, and improve visualization in modular prefabricated construction projects within mountainous environments?

More generally, the research examines the advantages and disadvantages of including BIM 4D and XR technologies into a pragmatic building project. It also evaluates the project in terms of visual clarity, efficiency, and coordination of which these technologies support current support. This paper aims to investigate the ways in which enhanced visualization, logistics optimization, and real-time decision-making development of digital tools could help to improve building processes. This is especially important in fields where traditional methods are limited in their capacity to function in far-off surroundings. Apart from this, it analyzes the relative advantages of several augmented reality (AR), virtual reality (VR), and mixed reality (MR) technologies to identify which of them best serves the several stakeholders engaged in the building process. The study comes to the conclusion with an emphasis on the primary issues that need to be resolved if XR technologies in building management are to be adopted successfully. These difficulties cover tool adaptation to fit the reality of actual projects, usability, and interoperability.

1.2 State of the Art

Particularly in connection with the application of building information modeling (BIM), digital twins, and automation, research on the integration of digital technologies into construction management has been growing in recent years. Because BIM 4D performs in the domains of project sequencing, clash detection, and cost estimation, it has attracted a lot of study. It offers a methodical way for organizing building projects' planning and execution. Exploratory research on the interaction of BIM with immersive technologies such as XR is still in its early phases.

According to the literature now in publication (Zhao et.al., 2023) , virtual reality (VR) helps stakeholders see designs and spot mistakes before actual construction starts, so benefiting them during the pre-construction stage. Real-time comparisons between planned and actual building are now feasible by means of augmented reality (AR) applied to on-site monitoring of development. MR offers solutions for interactive site coordination and dynamic workflow changes, so bridging the gap between the digital and physical worlds even though it has not been extensively investigated. The lack of empirical validation and real-world application creates a research void in knowledge on how XR and BIM might be used in challenging surroundings, such remote or mountainous building sites. This is so even if these developments have been achieved.

Particularly in cases involving prefabrication, modular construction, and off-site manufacturing, further well investigated are the difficulties the building sector faces in terms of transportation and logistics. For sites that are difficult, prefabrication is a sensible approach since it helps to save resources by lowering the time and effort required on-site during building. Still up for debate, though, is how much digital tools help to maximize logistics. This is particularly relevant when considering air transportation, such the use of helicopters for module delivery in line with Piedicavallo case study criteria.

This thesis aims to systematically integrate BIM 4D and XR to extend the current body of knowledge for the aim of construction planning and execution in logistically limited environments. This will be achieved by expanding on already conducted research.

1.3 Contributions

This dissertation makes a contribution to the broader fields of construction management, digital construction, and immersive technologies in several different aspects. Above all, it presents a fresh approach for merging XR technologies with BIM 4D. This framework shows how these instruments may be applied for real-time execution and logistics management as well as for pre-construction planning. Contrary to the assumptions that XR technologies are mostly beneficial for design validation, Mixed Reality (MR) can be used as an interactive tool for on-site decision-making and workflow coordination. This study shows that Mixed Reality (MR) can really fulfil these functions.

Moreover, this thesis offers empirical insights by means of a real-world case study carried out in a remote mountain environment. This goes on top of the theoretical contributions it generates. Previous studies mostly focused on the uses of BIM and XR in industrial or urban environments. This work enhances current knowledge by employing these technologies for modular prefabricated construction in challenging locations. Particularly in projects when ground transportation is not practical, the results clarify how XR might be used to improve the efficiency of logistics, the accuracy of material placement, and the communication between stakeholders.

Starting with surveying and modeling and working through scheduling, visualization, and simulation, the study also reveals a methodical approach to the integration of digital tools throughout the several phases of the building process. This work seeks to provide a practical handbook for the next BIM-XR implementation projects. This is achieved by methodically assessing the applicability of every digital tool for several building sector players.

1.4 Structure and Sequence of Chapters

The thesis is organized such that it helps to enable logical development from theoretical roots to practical application and evaluation (See figure1). The first chapter contains an introduction, a definition of the goals, and the research issue as well as other elements. This chapter clarifies the past knowledge and the reasons behind further research. Then the chapter State of the Art provides a comprehensive overview of the current corpus of knowledge on digital construction management, BIM 4D, and XR application uses. This work highlights the gaps in what is now under investigation and brings it into line with a more general scholarly debate.

The chapter on Case Study opens the Piedicavallo, Italy project site. It defines the surroundings as well as the logistical difficulties and accessibility restrictions the site presents. This chapter also offers a justification for using a modular prefabricated building technique and the integration of digital tools into the process, so clarifying the design approach.

Within the Methodology chapter, a substantial amount of information is presented regarding the numerous methods that can be utilized for data collection, modeling, and simulation. An explanation of the technological tools that were utilized is provided in this chapter. Some examples of these tools include the implementation of BIM modeling in Autodesk Revit, the sequencing of construction in Navisworks, and the development of augmented reality applications through the utilization of Twinmotion, Unity, and Magic Leap 2. The organization of construction management simulations is another topic that is covered in this chapter. Gantt charts and other scheduling tools are utilized at various points throughout the simulation.

The results of the digital workflow evaluation are detailed in the Results chapter. This chapter includes an analysis of the contributions of each XR application (VR, AR, and MR) to the different phases of construction design and management. The chapter also assesses the document's significance for construction stakeholders, offering insights into the most effective tools for project coordination and execution.

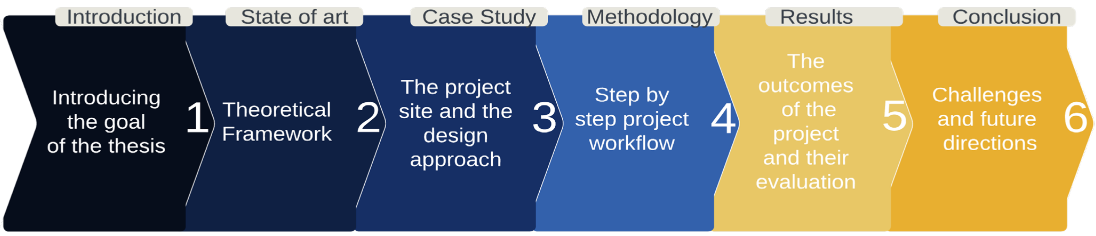


Figure 1. *The structure of the thesis.*

1.5 Summary

This paper explores the application of Extended Reality (XR) and Building Information Modeling (BIM) 4D in the field of construction management with special focus on the improvement of workflow efficiency, optimization of logistics, and visualization. This work helps to keep digital building technologies developing by means of a methodical approach and evaluation grounded on simulation. Furthermore, advantageous is it opens the path for data-driven, immersive, more efficient management systems.

This thesis offers a notable increase in the body of knowledge already in use on digital construction management by means of both theoretical contributions and empirical insights. Besides this, it offers direction on how to practically apply BIM-XR approaches in challenging surroundings. The conventional wisdom holds that XR's contribution is only that of design visualization; nevertheless, the results imply that Mixed Reality (MR) could be a tool for on-site coordination, so contradicting the wisdom. By means of a methodical approach and evaluation grounded on simulation, this work helps to continuously advance digital building techniques. Furthermore, it opens the path for more efficient building management systems depending on data and immersive design.

2. State of the Art

2.1 Extended Reality (XR) overview

Representing a continuum of immersive technologies that blur the boundaries between the physical and digital worlds, Extended Reality (XR) is an umbrella term spanning Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) (see Figure 2). XR technologies let users experience and interact with virtual or augmented environments effortlessly merging real and virtual elements in MR (Muñoz-Saavedra, Miró-Amarante, & Domínguez-Morales, 2020). From totally immersive virtual spaces in VR to integrating digital overlays into real-world environments in AR.

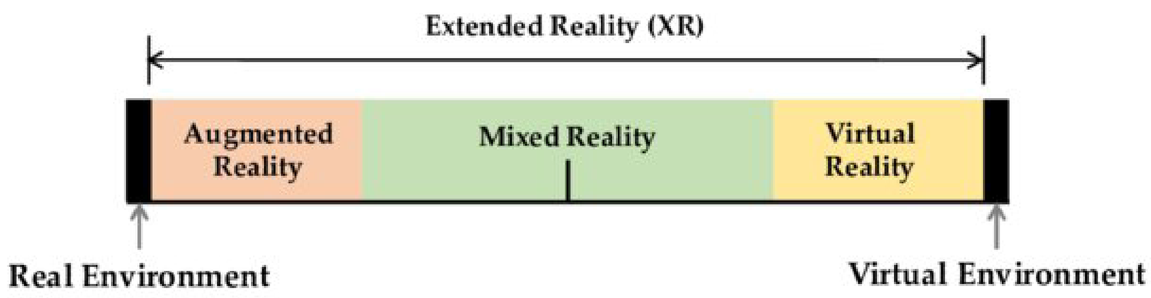


Figure 2. *The spectrum of VR, AR, and MR Fields (Zhao et.al., 2023)*

2.2 Virtual Reality (VR)

VR is a remarkable technology that allow you to enter digital worlds. It generates virtual worlds where you might investigate locations that seem real or even ones beyond our knowledge. Fundamentally, VR seeks to replace your real-life surroundings with a virtual experience—either a lifelike simulation or an entirely imagined vision of reality (Asham, Bakr, & Emadi, 2023).

VR is fundamentally all about “telepresence”— that is, it’s like you’re physically there in a digital environment. VR is centered on our perception of these experiences, Steuer says, allowing users to explore virtual worlds as though they were really within them (Steuer, 1992, as cited in Muñoz-Saavedra, Miró-Amarante, & Domínguez-Morales, 2020). Here the big concept is “building a perceived reality.” VR headsets are meant to nearly vanish the line separating the virtual from the real world. VR transports you—visually, sometimes with sound and touch—to feel as though you have entered another planet. It’s this ability to transport you somewhere completely new that makes VR such a powerful and exciting technology.

Historical views of VR show it as an effort to create environments where interactions seem real. This virtual environment would allow for the three-dimensional manipulation of digital data, providing a more immersive experience with both engagement and interaction at its core (Rebbani et al., 2021). One of the innovators of this concept, Ivan Sutherland, envisioned an “Ultimate Display,” one where virtual objects could behave like their physical counterparts and give us a sense of reality that is more than just passive (Rebbani et al., 2021).

It’s important to remember that VR is also about bending sensory and perceptual cues to create interstitial spaces that make you feel that the environment around you is alive and reactive. This virtual reality possesses an immersive quality that makes VR not just a means to escape into new forms of entertainment, but also into scenarios and circumstances that may be impractical or impossible in the results. VR, to that end, brings the core promise of offering novel experiences, perspectives, and opportunities to users that change the way of perceiving and interacting with reality (Muñoz-Saavedra et al., 2020).

VR has turned into a yardstick for how digital constructs can mimic reality while suggesting both human perspective and underlying potential lead(s) to expanded experiential knowledge (Asham et al., 2023; Rebbani et al., 2021).

2.3 Augmented Reality (AR)

AR is a disruptive technology that enhances the real-world surroundings of a user by integrating a digital element. This technology will enable us to merge virtual content into our surroundings and to do so as smoothly as possible — making it feel like a digital extension, rather than a redirection from reality. Augmented Reality allows users to remain anchored in the real world while interacting with digital content to contextualize a naturally integrated interface between reality and the digital (Asham, Bakr & Emadi, 2023).

In 1997, Azuma took early steps toward the current explanation of AR as a type of interactive 3D model that merges the realms of real and virtual entities. Where Virtual Reality (VR) creates a fully immersive experience that distorts the real world, AR enhances your current environment with useful digital overlays — text, images or objects that are added to the physical world that you see. This allows you to fulfill information requests or perform tasks without breaking contact with the environment (Muñoz-Saavedra, Miró-Amarante, & Domínguez-Morales, 2020).

The milestone was when Tom Caudell introduced AR technology in industrial applications back in the early 1990s. He replaced traditional tools with head-mounted displays at Boeing that projected wiring diagrams directly onto workspaces. It revolutionized the way information was displayed and applied and transformed AR from a theoretical idea to an effective and practical tool (Rebbani et al., 2021).

The hidden side of AR is its ability to overlay interactive digital frosting over the real world. AR lets users smoothly interact with a virtual world; hence it is essentially different from passive technologies. This unique capacity makes it a strong asset in fields including design, health care, entertainment, education, and in AEC (Architecture, Engineering and Construction) (Muñoz-Saavedra et al., 2020).

By blending the digital and physical worlds, AR provides richer experiences and bridges gaps in information and accessibility. Its ability to enhance how people see and interact with their surroundings has established AR as a transformative technology, driving innovation and changing how we learn and solve problems (Asham et al., 2023; Rebbani et al., 2021).

2.4 Mixed Reality (MR)

Mixed Reality (MR) is an advanced technology that takes elements from both the real and virtual worlds to create a composite world where users can interact with virtual and real objects in real time. Placed in the "Virtuality Continuum" created by Milgram and Kishino, MR is placed between entirely physical environments and entirely immersive virtual reality, enabling the two to be merged effortlessly (Muñoz-Saavedra, Miró-Amarante, & Domínguez-Morales, 2020).

MR is distinct from comparable technologies in that it supports interaction with virtual and real objects simultaneously. For example, virtual objects in MR environments not only co-exist with real objects but also respond to their surroundings, thereby facilitating more dynamic and context-aware interactions. This interaction takes AR's augmentative layering one step forward because MR allows for a reconciliatory space wherein virtual and real objects interact purposefully (Asoodar et al., 2024).

One of the most exciting possibilities of MR is that it can transform user interaction by enabling shared environments in which virtual objects can be interacted with as if they are real. This will also have profound implications for use cases like education, healthcare, and design, where realistic simulation and co-problem-solving count the most (Rebbani et al., 2021). For instance, in medical education, MR allows students to practice complicated surgeries by performing them on very detailed virtual anatomical models overlaid on real-world instruments and environments (Asoodar et al., 2024).

MR development has been directly tied to advances in sensor technologies and head-mounted displays enabling the precision and immersion necessary for real-world applicability. The technology bridges the physical-digital divide by generating environments within which the boundaries between the two worlds are invisible, but complementary and operational (Muñoz-Saavedra et al., 2020).

Mixed Reality brings the real and digital worlds together in a way that feels natural and smooth. This exciting technology has the power to solve tough problems by making things more interactive and immersive. By connecting what's real with what's virtual, MR changes how we interact with the world around us. (Asoodar et al., 2024; Rebbani et al., 2021).

2.5 Tools, Technologies, and Software Driving XR

An ecosystem of specialized hardware, software, and integration tools underpins the evolution of AR, VR, and Mixed Reality (MR) technologies. These technologies are crucial in creating interactive and immersive experiences in many different spheres. Still, they have great difficulties including hardware complexity, accessibility, and usability problems notwithstanding their potential.

2.5.1 Hardware Technology

To carry out better study of the thesis and to know what widgets there are in the lab, information about the technologies that have been developed and exists on the market has been gathered and summarized (See Table 1). With this knowledge it is more efficient to process on what purposes and which technology can be used to carry out the tests.

Within the virtual reality space, the **Meta Quest 3** is unique as a stand-alone VR helmet driven by the Snapdragon **XR2 Gen 2** platform that provides advanced spatial audio and high-resolution visuals of 2064 × 2208 per eye. The **HTC Vive Pro 2** boasts a broad 120-degree field of vision and an impressive 5K resolution (2448 x 2448 per eye), which makes it suitable for professional applications like simulation training. The **Valve Index** enhances user involvement by using finger-tracking controllers and a 144Hz refresh rate, providing a more realistic virtual world experience.

Turning now to augmented and mixed reality head-mounted displays, the **Microsoft HoloLens 2** uses 43-degree diagonal field of view and SLAM technology for exact spatial mapping. Designed for business uses, the **Magic Leap 2** has dynamic dimming features that improve view in mixed-reality environments.

Many times, interaction and input devices define immersion technology. **Oculus Touch Controllers** and **Valve Index Knuckles** increase VR interactivity by means of motion tracking and advanced finger tracking respectively. The **Leap Motion Controller** lets users directly interact with virtual objects with its real-time hand tracking and merged hand tracking in devices like the **Meta Quest 3** and **Microsoft HoloLens 2**.

Devices like the **HTC Vive Pro Eye** maximize visual experience by focusing processing capability where the user looks, so enhancing performance. In training and gaming environments, **HaptX Gloves** and the **bHaptics TactSuit** provide realistic tactile feedback that is quite helpful.

LiDAR and **SLAM** are among spatial mapping technologies that greatly help to create accurate 3D environment maps—needed to match virtual and real-world elements. Further improving depth-sensing capabilities are **Intel RealSense** cameras, which track complete spatial data for exact object recognition and interaction in augmented reality applications.

Display technologies are also rather important; devices like the **Meta Quest Pro** use mini-LED technology to increase brightness and contrast and the Valve Index uses dual LCD panels to create sharp images. Found in devices like the **Meta Quest Pro** and **Nreal Light** respectively, optics innovations like pancake lenses and waveguide displays lower helmet bulk while maintaining visual clarity.

Furthermore, enhancing the realism of virtual interactions is the tactile sensations provided by haptic and sensory feedback systems like **Ultrahaptics** and the **SenseGlove Nova** using force feedback and ultrasonic waves. **Teslasuit** and other full-body haptic suits replicate environmental effects, so improving the immersive training settings.

Overall, developments in networking and connectivity—such as Wi-Fi 6/6E and 5G integration—shown in devices like the **Meta Quest 3** and **Nreal Air** guarantee low-latency streaming and seamless cloud-based rendering, so essential for delivering high-quality, responsive experiences in wireless VR and AR settings.

Table 1. Summary of Hardware Technologies:

Name	Use	Widget	Present in Lab	Year	Price Range	Best Quality
Leap Motion Controller	Motion Capture	Hand-tracking sensor	YES	2013	$89	Real-time hand tracking
Ultrahaptics	Haptic Feedback	Non-wearable haptic system		2013	Varies	Ultrasonic waves for touch
Intel RealSense	Motion Capture	Depth-sensing camera	YES	2014	Varies	Depth sensing, object tracking
Oculus Touch Controllers	Controller	Handheld controller	YES	2016	Included with Rift	Motion tracking
Teslasuit	Haptic Suit	Wearable haptic suit		2018	$12,999	Full-body environmental effects
Valve Index	VR	Headset		2019	$999	144Hz refresh rate, finger tracking
Valve Index Knuckles	Controller	Handheld controller		2019	$279	Advanced finger tracking
Microsoft HoloLens 2	AR/MR	Headset		2019	$3,500	SLAM tech, spatial mapping
HTC Vive Pro Eye	VR	Headset		2019	$1,599	Eye-tracking for performance
bHaptics TactSuit	Haptic Suit	Wearable haptic suit		2019	$499	Full-body tactile feedback
Nreal Light	AR/MR	Headset		2020	$599	Waveguide display for clarity
HTC Vive Pro 2	VR	Headset	YES	2021	$1,399	5K resolution, 120° FOV
Nreal Air	AR	Headset		2021	$379	5G integration for low latency
SenseGlove Nova 2	Haptic Feedback	Wearable gloves		2021	€ 5,999	Force feedback
Magic Leap 2	AR/MR	Headset	YES	2022	$3,299	Dynamic dimming for visibility
Meta Quest Pro	VR/MR	Headset		2022	$999	Mini-LED, pancake lenses
Meta Quest 3	VR/MR	Headset	YES	2023	$499.99	Quality-price
HaptX Gloves G1	Haptic Feedback	Wearable gloves		2023	$4,500 – $5,495	Realistic tactile feedback

2.5.2 Software Platforms

Game engines and XR development tools play an important role in creating stunning experiences in virtual, augmented, and mixed reality. **Unity 3D** is one of the most powerful tools for XR developers because of the XR Interaction Toolkit, which drives projects with real-time rendering and multi-platform support. With its XR Interaction Toolkit—which provides real-time rendering, cross-platform compatibility, and access to a big asset store for pre-built components—unity supports VR, AR, and MR applications. Usually starting with this decision, developing experiences on devices like the **Oculus Quest**, **HTC Vive**, and **Microsoft HoloLens** starts with renowned for its high-fidelity graphics and ability to create visually amazing XR apps, **Unreal Engine** is another powerhouse on the field. **Unreal Engine** is famous for its graphics and is a strong contender in making impressive XR applications. It can be used for many things like creating 3D models for buildings, video games, and training simulations. That's why it's the preferred tool for projects that require high quality graphics.

Platforms such as **ARCore** and **ARKit** rule the mobile AR scene for XR-specific development. Designed by Apple, **ARKit** provides scene tracking, object detection, **LiDAR** integration for exact spatial mapping, so enabling AR app creation for iOS devices. It also supports sophisticated features including motion capture and people's occlusion. From the Android side, Google's **ARCore** offers motion tracking and environmental awareness to place virtual objects in the actual world. It's a strong choice for Android AR development since it offers tools for depth sensing, light estimation, and virtual object anchoring as well as for Concurrently, the open-source **Microsoft Mixed Reality Toolkit (MRTK)** is meant for MR applications, mostly for **HoloLens**. It offers elements for spatial mapping, hand tracking, eye-gaze interaction, so simplifying the design of immersive MR experiences. Another interesting tool is **Vuforia**, an **AR** development tool supporting both marker-based and markerless AR experiences. With features including model tracking, object recognition, and overlay of 3D models onto real-world objects, Vuforia finds extensive use in industrial and commercial applications.

Additionally, becoming popular are cloud-based XR systems, which allow scalable immersive experiences and team projects. One platform for building shared virtual environments where users may host meetings and events is **Spatial.io**. It lets users join VR headsets or web browsers, so promoting cross-platform interaction. **Amazon Sumerian** is another cloud-based tool simplifying the development of 3D, virtual reality, and augmented reality apps. By allowing cloud-generated scenes for mobile and web platforms, it eliminates the need for specific hardware. Perfect for cooperative AR projects including ongoing AR content, **Microsoft Azure Spatial Anchors** provide a cloud-based solution for storing and accessing spatial data.

Within the simulation and prototyping space, tools like **Unity Reflect** and **Gravity Sketch** are revolutionizing sectors. Building Information Models (BIM) in AR and VR are visualized using Unity Reflect, so facilitating real-time Autodesk Revit collaboration and integration. Conversely, Gravity Sketch is a 3D design tool for VR, extensively applied in sectors including automotive design and product development to produce models and prototypes. **Mozilla Hubs** provides a web-based platform available from VR headsets, desktop computers, or mobile devices, so enabling shared virtual spaces and a flexible tool for social interaction and collaboration.

Customized for XR, content management systems (CMS) meeting business and educational requirements are also starting to surface. Designed for corporate training and collaboration, **Vizible** VR content management system lets nondevelopers create and distribute VR presentations and training scenarios. Likewise, **Innoactive Creator** is a VR training workflow management tool that helps to produce detailed training courses for industrial uses. **ZapWorks** offers a complete CMS for AR content that supports marker-based and **WebAR** experiences, so enabling tools for developing interactive AR campaigns in marketing and education.

XR systems are progressively including artificial intelligence (AI) to improve user interaction and realism. For immersive uses, **IBM Watson XR** adds artificial intelligence capabilities including speech recognition, natural language processing, and emotional detection. Combining AI-driven gaze tracking and interaction models, **Pico Interactive SDK** presents real-time user engagement in VR environments. Simultaneously, **NVIDIA Omniverse** is a useful tool for XR production since it allows one to replicate real-world physics and create photorealistic environments.

At last, tools for cross-platform development are streamlining the design of XR experiences compatible for several devices. Facebook's **React 360** framework lets developers create cross-platform 360-degree VR experiences using React, so facilitating the deployment of VR apps on desktop and mobile platforms. By allowing **WebXR** content to be created straight in browsers, lightweight JavaScript tool **Three.js** supports VR and AR experiences without needing separate apps. Designed by the Khronos Group, **OpenXR** provides developers seeking compatibility across several XR devices with a consistent framework for building apps that run naturally across many platforms.

By enabling creators to create immersive, interactive, scalable experiences across industries, these tools and platforms taken together are motivating XR development. From gaming to training to design to teamwork, the XR technologies ecosystem keeps expanding and offers new chances for our interaction with both digital and physical surroundings.

Table 2. Summary of Software Technologies:

Software/Platform	Primary Function	Key Features	Best For
Unity 3D	Game Engine & XR Development	XR Interaction Toolkit, real-time rendering, asset store	VR, AR, MR apps, cross-platform
Unreal Engine	Game Engine & XR Development	High-fidelity graphics, real-time rendering, simulation	High-quality graphics, simulations
ARKit	Mobile AR Development (iOS)	Scene tracking, LiDAR, object detection, motion capture	AR apps for iOS devices
ARCore	Mobile AR Development (Android)	Motion tracking, environmental awareness, depth sensing	AR apps for Android devices
Microsoft MRTK	MR Development Toolkit	Spatial mapping, hand tracking, gaze interaction	HoloLens & MR applications

Vuforia	AR Development Tool	Marker-based & markerless AR, object recognition	Industrial & commercial AR apps
Spatial.io	Cloud-based XR Collaboration	Virtual meetings, multi-device support	Business meetings, remote teamwork
Amazon Sumerian	Cloud-based XR Development	No specialized hardware needed, 3D web & mobile AR/VR	Scalable XR experiences
Microsoft Azure Spatial Anchors	Cloud-based Spatial Mapping	Persistent spatial data, AR content management	AR content sharing, enterprise AR
Unity Reflect	XR for BIM & AEC Industry	Real-time Autodesk Revit integration	Architecture, construction (BIM)
Gravity Sketch	3D Design & Prototyping (VR)	3D modeling in VR, automotive & product design	Industrial design, prototyping
Mozilla Hubs	Web-based VR & Social XR	Multi-user VR spaces, web-based access	Virtual collaboration & interaction
Vizible VR	VR Training & Content Management	No-code VR creation, corporate training	Business training & presentations
Innoactive Creator	VR Training Workflow Management	Industrial VR training course creation	Manufacturing & industrial training
ZapWorks	AR Content Management & WebAR	Interactive AR campaigns, marker-based/WebAR	Marketing & education
IBM Watson XR	AI-Powered XR	Speech recognition, NLP, emotional detection	AI-driven immersive experiences
Pico Interactive SDK	AI & XR User Engagement	AI-driven gaze tracking, real-time interaction	VR user engagement & analytics
NVIDIA Omniverse	XR Production & Physics Simulation	Real-world physics, photorealistic rendering	High-end XR content creation
React 360	Cross-Platform VR Development	Web-based VR experiences, React framework	Browser-based VR apps
Three.js	WebXR & Lightweight 3D Content	JavaScript-based 3D rendering for VR/AR	Web-based XR experiences
OpenXR	XR Development Standard	Unified API for cross-platform XR apps	Compatibility across XR devices

2.5.3 Critical Observations and Challenges

Although Extended Reality technologies have great potential, their hardware and software architecture create certain difficulties. The expense of XR tools—especially head-mounted displays (HMDs)—is one of the toughest challenges. More sensible for use in companies and institutions than by personal consumers, high-end devices like the Microsoft HoloLens 2 and HTC Vive Pro 2 are simply too costly for most people (Muñoz-Saavedra, Miró-Amarante, & Domínguez-Morales, 2020). Further adding to this financial obstacle is the requirement for more equipment, such as tracking systems or strong computers, which makes acceptance especially challenging.

Additionally, a major obstacle for XR devices are ergonomic problems. Many HMDs are heavy and uncomfortable to wear for long periods; they frequently cause overheating, neck strain, and tiredness. Another frequent issue is motion sickness, particularly in virtual reality environments where what users see does not always correspond with what they feel. This especially stands out in VR settings with low frame rates or high latency (Asoodar et al., 2024). Long-term use of XR devices is difficult for these physical discomforts.

Technologies used for spatial mapping and tracking, such as SLAM and LiDAR, have their limitations. Their reliability often decreases in environments with poor lighting or reflective surfaces, where they struggle to function accurately. Furthermore, their great computing needs strain hardware, occasionally resulting in performance problems or limiting these systems to high-end devices (Rebbani et al., 2021).

Interaction tools meant to enhance immersion, such as haptic feedback devices and hand-tracking systems, also present their own set of difficulties. These technologies keep getting better, but occasionally in more demanding settings, they lack responsiveness or accuracy. Hand-tracking tools like Leap Motion, for example, might find it difficult to precisely capture complex finger motions or detect motions in low light. Similarly, haptic feedback devices are still unable to replicate fine textures or provide precise force feedback, which limits the realism of virtual interactions.

From the standpoint of software, XR content creation and management systems are occasionally disorganized and complex. Developers must negotiate high learning curves and compatibility issues since they must regularly create several versions of the same application to operate across several devices and platforms. Cloud-based XR tools have latency and high bandwidth requirements even if they offer scalable and collaborative uses. Privacy concerns about the storage and distribution of spatial data—such as with Microsoft Azure Spatial Anchors—add still another degree of complexity (Asoodar et al., 2024).

2.6 BIM

Building Information Modeling (BIM) is revolutionizing the architecture, engineering, and construction (AEC) industry by offering a digital first approach to designing, running, and managing projects. Its interoperability creates seamless data exchange data with different software platforms, which ensures all project actors can access, share and utilize. Beyond only a tool, BIM is a process combining several technologies to create a quite accurate virtual model of a building, so capturing both its physical features and functional aspects (Azhar, 2011). Acting as a central knowledge center, this digital model improves cooperation among project participants and helps informed decision-making at every phase of a building's lifetime.

The adoption of BIM is proving to be a game-changer in overcoming long-standing challenges in the AEC sector, including inefficiencies, budget overruns, and disjointed communication. By adding extra dimensions like scheduling (4D), cost estimation (5D), and sustainability assessments (6D), BIM transcends simple 3D modeling unlike conventional CAD tools. From initial concept to construction and long-term facility management, these increased capabilities help to smooth out the change between project phases (National Institute of Building Sciences, 2017).

By streamlining workflows, minimizing material waste, and enhancing project efficiency, BIM represents a major shift in how buildings are designed and constructed. The National BIM Guide for Owners underscores the significance of implementing "BIM Done Right," emphasizing the need for clear objectives, strategic planning, and collaboration to maximize its benefits (National Institute of Building Sciences, 2017).

2.6.1 BIM integration with XR

BIM and XR are transforming the AEC sector by changing how projects are visualized, coordinated, and tracked in real time. Although XR improves user engagement by providing immersive and interactive experience, BIM shows itself in data organization and management. Still major obstacles, though, technical ones including model accuracy, data synchronizing problems, and slow industry adoption (Alwindawi, 2024; Pan & Isnaeni, 2024).

By combining BIM with XR, project visualization reaches unprecedented heights and stakeholders may interact with models long before building starts. Immersion design reviews made possible by VR help to lower mistakes and support smooth cooperation. AR then overlays BIM models onto actual building sites, allowing real-time tracking of development and collision avoidance. This improves data-driven decision-making (Pan & Isnaeni, 2024), lowers misinterpretation, and increases efficiency. However, AR's effectiveness relies on precise model alignment—an area where current tracking technologies still struggle, particularly in dynamic site conditions.

Despite its clear advantages, BIM-XR adoption remains hindered by hardware limitations, software integration challenges, and cost concerns. AR often experiences misalignment between virtual models and real-world elements, which can introduce differences in project execution. Particularly AR, sometimes finds alignment between virtual models and real-world components to introduce differences in project execution. Furthermore, limiting their impact on overall project management, most XR applications concentrate mostly on 3D visualization without fully integrating BIM's 4D and 5D capabilities (Alwindawi, 2024).

2.6.2 Focus on 3D and 4D

Acting as a multidimensional platform, BIM combines several project data into complete digital models. Among its several aspects, 3D and 4D BIM form the fundamental layers that enable project scheduling and design visualization respectively. These aspects reflect important facets of BIM's application in improving project planning, execution, and teamwork.

3D BIM: BIM's 3D dimension is mostly concerned with a project's geometric and spatial portrayal. It helps to create a digital model combining physical properties and interactions among building components. Unlike conventional CAD, which generates static two-dimensional drawings, 3D BIM offers an interactive and dynamic environment whereby stakeholders may see the project in a real-world context (Azhar, 2011).

Key advantages of 3D BIM are several and greatly improve the results of building projects. Architects and engineers can find design defects and disparities early in the process by seeing projects in three dimensions, so improve the design quality. Good project progress depends on stakeholders knowing better; this visualization helps to lower misinterpretation and enhance decision-making through better understanding. One single source of truth—a shared 3D model—allows seamless coordination between several disciplines, optimizing efforts of coordination. 3D BIM also allows authorities to review the model broadly, thus improving code compliance and approval procedures. Better project flow and reduced uncertainty are made possible by better alignment of project teams made possible by this enhanced visual clarity.

4D BIM: By including time-related data, 4D BIM expands conventional 3D modeling (See Figure 3) and lets building teams see and replicate project development all through its lifetime. 4D BIM improves project planning, coordination, and execution by tying scheduling data to 3D models, so lowering uncertainty and raising workflow efficiency. 4D BIM provides a dynamic, real-time view of building activity unlike traditional scheduling tools including static Gantt charts or network diagrams. This lets stakeholders better predict possible conflicts, maximize sequencing, and make wiser decisions (Aredah et al., 2021).

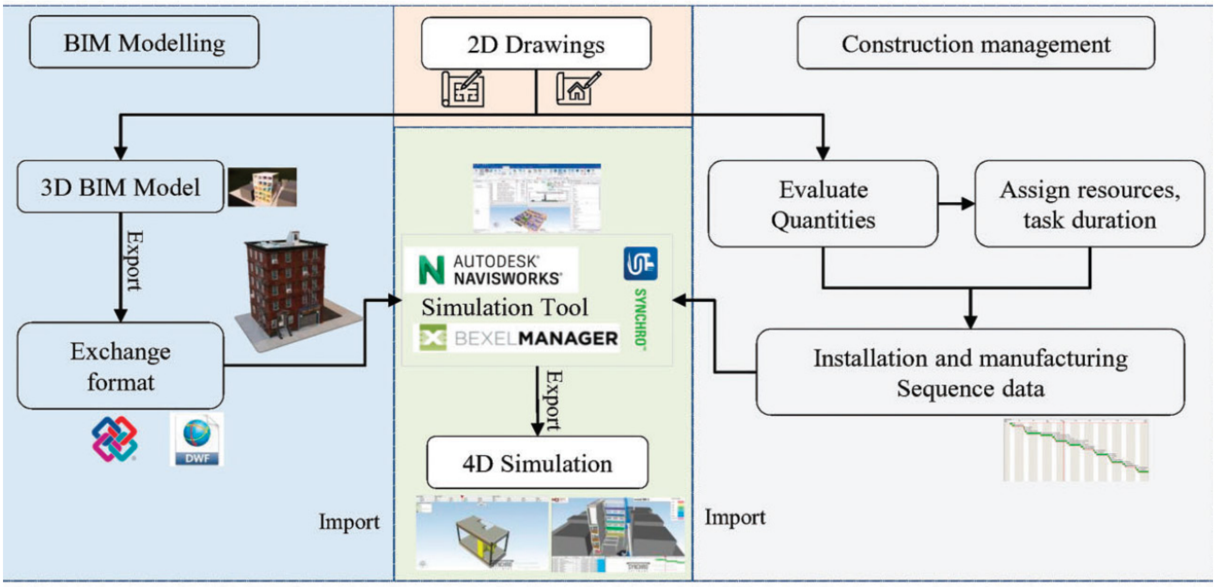


Figure 3. *Typical 4D BIM simulation development process (Rehman, Kim, & Choi, 2023)*

Many techniques are used, each with special benefits, to properly combine scheduling with BIM models. The two most often used approaches are the Critical Path Method (CPM) and the Location-Based Management System (LBMS).

CPM guides the minimum project duration and extensively used technique for scheduling and deciding the longest sequence of dependent activities. Combining CPM schedules with the BIM model into a 4D BIM environment allows project teams to see building sequences directly from the BIM model in real time. Early time-space conflicts detection made possible by this guide enables preventative actions. But CPM's reliance on task dependencies—without directly considering resource allocation and location-based constraints—may lead to inefficiencies in difficult projects.

LBMS offers a replacement for CPM by concentrating on the flow of people and resources over several project sites. LBMS guarantees a seamless transition between work zones, optimizing resource use unlike CPM, which gives task dependencies top priority, lowering idle time. LBMS helps designers in 4D BIM applications to see building sequences using location-based scheduling concepts, so guaranteeing a constant flow of work and avoiding congestion in particular areas.

One of the most important benefits of 4D BIM is its capacity to give stakeholders an interactive platform to investigate several scheduling options through real-time visualization of building progress. Simulating building sequences lets project teams evaluate several "what-if" situations, so improving processes and helping to proactively prevent possible delays. This capacity helps to lower miscommunication and enhance general project alignment utilizing a shared digital model that combines design, scheduling, and execution data, fostering better collaboration (Aredah et al., 2021).

By connecting time-based data to 3D models, 4D BIM will eventually change building planning by enabling dynamic scheduling and real-time visualization. By identifying bottlenecks, streamlining processes, and enhancing stakeholder coordination, the adoption of CPM and LBMS increases project efficiency. It is anticipated that as 4D Bim advances, its integration with emerging technologies—like artificial intelligence and real-time cloud computing—will increase its impact on the AEC industry, promoting more prudent and effective building practices.

2.6.3 The Role of Revit and Navisworks

BIM tools play a crucial role throughout every phase of a project's lifecycle, from initial design and visualization to construction management and long-term facility operations. The National BIM Guide for Owners (2017) highlights the importance of choosing the right tools to align with project requirements and stakeholder needs. Using a shared repository of data, these tools guarantee that all disciplines have access to current data as the project develops, so they improve accuracy, productivity, and error reduction.

Leading BIM tools like Autodesk Revit and Navisworks are now vital for modern building techniques. These advanced technologies allow the integration of difficult data sets and help to produce complete parametric models. Through analysis, clash detection, and project visualization, they also help teams to resolve design issues and ensure suitable coordination of all elements before the beginning of construction. Using these powerful tools will help BIM professionals simplify procedures, lower risks, and generate better project results at all levels (Azhar, 2011).

Autodesk Revit: It is a breakthrough in the field of Building Information Modeling (BIM), transforming our design, management, and bringing to life construction projects. Revit is essentially a parametric modeling tool that goes beyond simple 3D design. For builders, engineers, and architects, it is a required tool since it lets users create detailed models combining geometry with rich metadata. By allowing dynamic updates, real-time teamwork, and perfect integration across many disciplines, Revit distinguishes itself from more conventional design tools. This not only raises design quality but also simplifies procedures, so supporting projects aiming at greater success all around.

Among Revit's best phasing and scheduling tools are those that let users exactly see and control building sequences. The phasing function lets builders assign building components to specific building phases, so generating an unambiguous, methodical project schedule. This is especially useful for complex projects involving several phases since it provides a complete study of actions over time. The scheduling features link model components straight to building activities, thus extending their influence. Any design modification automatically updates the schedule, so lowering hand-made mistakes, enhancing accuracy, and supporting better decision-making all through the project lifetime.

Another great tool that Revit serves with is terrain modeling which was handy for the thesis. Its tools enable users to precisely view, create, and alter topographical surfaces. By importing survey data, teams can build thorough site models and change terrain features to match construction needs— that is, grading or cut-and-fill calculations. The updated terrain tools of Revit now enable even more complex site designs, so enabling a complete representation of landforms and their interactions with building components.

Navisworks: Designed for model aggregation, coordination, and clash detection, Autodesk Navisworks is the ideal partner for Revit. It combines ideas from many fields—architecture, structure, MEP, and more—into one, cohesive environment. Long before construction begins, this integration allows one to identify spatial conflicts, that is, a pipe running across a beam or ductwork clashing with structural elements. Teams can save time and money by spotting and fixing these problems during the design stage, so avoiding costly rework and delays down the line.

Navisworks continues, though. It also introduces 4D scheduling—that which links model components straight to building schedules. This lets teams design graphic simulations for the development of the project, so providing a clear image of how the construction will turn out over time. These simulations keep projects on schedule, maximize resource allocation, and help to streamline building sequences.

All taken together, Revit and Navisworks form a strong team that guarantees improved outcomes, lowers risk, and streamlines project delivery. Whether you are managing a multi-phase building project or planning a skyscraper, these instruments cooperate to simplify and speed up the process. Both tools are crucial specifically for the thesis, which led to understanding construction management visually and thinking of the solutions for the obstacles encountered during the study.

2.7 Construction Management

Construction Management (CM) is the backbone of turning a design into a real, physical structure. It's the discipline that takes charge during the final phase of a project, ensuring everything runs smoothly until the building is handed over to the owner. But the role of construction management goes far beyond just overseeing the building. Not only is it responsible for a wide range of tasks, from scheduling materials and coordinating crews to managing timelines, ensuring site safety, and keeping costs under control, but also verifies installations, updates documentation, and plans the construction site layout. CM essentially ensures the project runs from beginning to end on schedule.

One of the key tools of CM is the use of a breakdown structure. This helps to break out challenging projects into more reasonable pieces. Work Breakdown Structure (WBS) breaks out large project components—such as disciplines, deliverables, or categories—into smaller, more manageable tasks until every last detail is taken into account. For team and resource management the Organization Breakdown Structure (OBS) is also available; for financial planning the Cost Breakdown Structure (CBS). These systems help one to keep all orderly and on target.

While managing time and money, Gantt charts are an effective tool for construction managers. A Gantt chart presents a graphic project chronology unlike WBS, which focuses on task breakdown. It displays, using horizontal bars, the start and end times, length, and necessary resources of employment. This makes tracking expenses as the project moves forward simple, allocating resources efficiently, and closely monitoring development clear-cut.

These ideas become even more important in a BIM environment, where building managers may improve planning and execution using 4D and 5D dimensions. Directly including cost data and scheduling into the BIM model will help them to replicate project timelines, maximize resource allocation, and guide decisions all through the building process. This integration guarantees the project stays on time and within budget by helping to avoid expensive errors and so increases efficiency.

2.7.1 Understanding Work Breakdown Structure (WBS)

One tried-and-true approach to boost output and remain orderly is breaking large projects into smaller, doable chunks. In the discipline of project management, the WBS formally embodies this approach. Thinking of WBS as a road map guiding a big project toward more doable smaller divisions. It's a hierarchical framework that starts with the big picture and drills down into finer and finer details, making sure every part of the project is accounted for. By tying together scope, cost, and schedule baselines, WBS ensures that all the moving parts of a project are aligned, which makes planning, execution, and control much smoother. In short, it's a project manager's secret weapon for turning overwhelming tasks into something easier to track, estimate, and manage. (Khowja et.al., 2020)

WBS is not limited in any one sector or kind of project; rather, it is not limited at all. From building a skyscraper to releasing a software product to organizing a large event, WBS can be practically used almost anywhere. Well defined project divisions enable responsibility and clarity by themselves. Teams can see exactly what must be done, who is in charge of what, and how all of this fits. Independent of project size or complexity, this helps with tracking of development, workload management, and maintaining the project on schedule.

A well-defined WBS lays the foundation for effective project management. Below are the key steps to create a WBS:

1. **Defining the Project Scope and Objectives:**
Starting with exactly defining the project goal, deliverables, and expected outcomes. Clearly defined scope helps to prevent scope creep by ensuring that all stakeholders share common knowledge of the project goals.

2. **Identifying Major Deliverables and Phases:**
Divining the project into high-level deliverables or phases mirroring the key components required for completion reflects the main elements. Usually, these fit the phases of the life cycle for the project and its benchmarks.

3. **Decomposing Deliverables into Smaller Work Packages:**
Every high-level deliverable should be broken out into more doable tasks or work packages. These should be specific enough to allow proper assignment of responsibilities and correct tracking of development.

4. **Assigning Ownership and Responsibilities:**
Obviously assigning tasks to relevant teams or departments. Every work package should have an owner assigned in charge of quality assurance, reporting, and implementation.

5. **Establishing Task Dependencies:**
Indicate the connections between several tasks and establish dependencies (task B cannot start until task A is completed). Good scheduling and risk management rely on a knowledge of dependencies.

6. **Integrating WBS with Cost and Time Estimation:**
Attaching to every work package approximation of time and resource allocation. This phase ensures the WBS's link to baselines for schedules and project costs.

7. **Creating Visual Representation:**
Building a WBS is either graphically showing a hierarchical diagram, tree structure, or outline. This helps all the stakeholders to communicate better, align themselves, and simplify their understanding.

8. **Validating and Refining the WBS:**
Using a WBS review including significant stakeholders, one exercises completeness, accuracy, and feasibility. Any questions or overlooked details should be polished before choosing the building.

Project planning, execution, and monitoring all depend much on a well-ordered WBS. Methodically breaking out work into reasonable chunks helps to improve clarity, responsibility, and efficiency even as it reduces risk and uncertainty. Good WBS implementation guarantees that projects are trackable, well-organized, in line with strategic objectives, so enabling efficient project completion.

2.8 Extended Reality in Construction management and in other fields

Among other XR technologies, AR, VR, and MR are becoming rather common in many different fields. Mostly with an eye toward surgical and anatomical training, XR has been used in almost 184 studies in the healthcare industry; it has shown good effects on cognitive and psychomotor skills (Asoodar et al., 2024). In education, VR and AR are used widely, with applications spanning STEM fields and skill development; engineering education sees robust adoption in areas like electrical circuit visualization and virtual labs, improving student engagement and learning outcomes (Asham et al., 2023). The creative arts sector leverages XR for virtual galleries, AR-enhanced public art, and immersive theater, redefining artistic expression and audience interaction (Wang et al., 2024). These statistics underline XR's transformative influence across domains (see Figure 4).

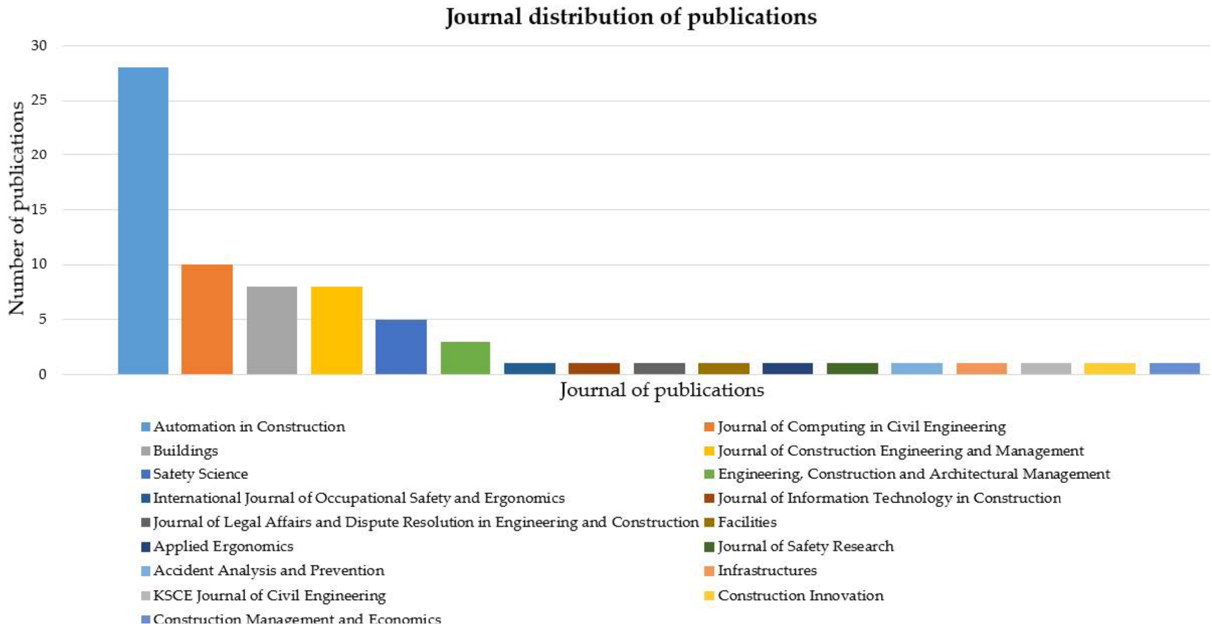


Figure 4. *Journal distribution of publications (Zhao et.al., 2023).*

2.8.1 The Role of Extended Reality in Construction Management

Beyond the conventional scope of project management, construction management is a diverse field including an integrated approach covering the whole lifetime of a building project. It means a dynamic interaction of planning, coordination, and control over many resources, including labor, materials, equipment, and financial investments, guaranteeing that project goals are reached under constraints of time, cost, and quality (Sima, 2024). By allowing real-time cooperation, proactive risk reduction, and better visualization, advanced technologies like Bimand XR have revolutionized building management (Ma, 2025). Notwithstanding these technical developments, inefficiencies including delays, budget overruns, and coordination conflicts still afflict building projects, so underlining the ongoing difference between theoretical models and actual application (Fu & Liu, 2018). Moreover, the growing complexity of building projects calls for an interdisciplinary approach including architecture, engineering, urban planning, and environmental issues, so supporting the need of a more complete and flexible management paradigm (Golparvar-Fard et al., 2010). Construction management is ultimately a constantly changing field requiring strategic foresight, technological adaptability, and stakeholder involvement to maximize project outcomes in an increasingly complex built environment, not only about completing a set of defined tasks.

Among XR's most useful instruments for building control are training and safety management. Studies have shown that VR and AR offer immersive training environments where employees might replicate dangerous building conditions without actual hazards (Li et al., 2024). Virtual Reality safety simulations, for instance, let employees engage in high-risk events—such as running heavy machinery or working at heights—without really running actual risks. This has especially helped to reduce on-site accidents by increasing hazard recognition and response times.

Project visualization and planning constitute still another vital component of XR application. Conventions in 2D blueprints and paper-based plans sometimes fall short in capturing the complexity of building projects. Using BIM-integrated VR and AR technologies, construction managers can immerse themselves in completely realized 3D digital models of projects before breaking ground, enabling real-time changes and stakeholder coordination (Ma, 2025). Microsoft HoloLens and other Mixed Reality (MR) technologies have been used to overlay digital models onto physical locations, enabling engineers and architects to undertake site assessments with improved spatial awareness (Woodward et al., 2010).

XR tools have been included with 4D BIM models in schedule and progress monitoring to replicate building sequences over time. Project managers especially benefit from this tool since it helps them to see possible bottlenecks and aggressively handle delays (Fu & Liu, 2018). AR apps on tablets or smart glasses, for instance, let site supervisors compare real-time progress with the planned digital twin of the project, so enabling quick identification and correction of deviations from the schedule in mobile construction site visualization (Deniz, 2019).

XR has also helped project participants to interact and coordinate far more dynamically. Conventional building management relies on paper documentation and in-person meetings, which may lead to misinterpretation and inefficiencies. Using VR-based virtual meetings, remote teams can review models and make design changes in real-time within a shared digital construction environment. This has especially been helpful in large-scale infrastructure projects whereby multidisciplinary teams are dispersed over several sites (Na, Aljagoub, & Webber, 2022).

Furthermore, helping clash detection and error avoidance is the XR-based integration with BIM. AR-assisted site walkthroughs help teams to find design conflicts between mechanical, structural, and electrical components before building starts. By lowering material waste and expensive rework, this preemptive error detection helps to improve sustainability and cost effectiveness in project implementation (Kamat et al., 2010).

Challenges and Issues

Although Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—Extended Reality (XR) technologies have greatly advanced construction management—their acceptance is not without difficulties. Many technical, financial, and organizational hurdles prevent their broad application even if they could improve project visualization, cooperation, and safety.

1. **High Implementation Costs:**
One of the main challenges to applying XR is the enormous expense related to hardware, software, and training. Modern VR headsets, AR-enabled smart glasses, and MR devices—like the Microsoft HoloLens—demand a significant upfront cost. Furthermore, creating custom XR applications that interact with Building Information Modeling and other project management systems comes with significant software development and maintenance expenses (Ma, 2025). Many small and medium-sized building companies find it difficult to justify these costs, thus adoption is mostly limited to big companies with enough means.

2. **Data Integration and Compatibility Issues:**
Technical challenges arise when XR is included in current building processes. Often running in different file formats and software environments, many building companies make use of several digital tools including BIM, CAD, and GIS, which is the issue of interoperability. One major difficulty is making sure XR apps complement these legacy systems (Deniz, 2019). Additionally, real-time synchronization of project data between on-site AR tools and cloud-based management systems requires robust IT infrastructure, which many companies lack.

3. **Hardware Limitations and Field Deployment Challenges:**
Even with developments in AR and VR hardware, the practicality of using these devices on building sites is still an issue. Due to too much sunlight, AR-enabled smart glasses and MR headsets sometimes suffer from limited battery life, bulky form factors, and outdoor vision problems (Woodward et al., 2010). Common in construction sites, dust, vibrations, and high temperatures further reduce the lifetime and useability of XR devices. Furthermore, many XR solutions depend on consistent internet access for cloud-based data access—a need not always met at remote or large-scale building sites.

4. **Learning Curve and Resistance to Change:**
XR's successful application in construction calls for specific training; many building professionals have never used immersive digital technologies. Particularly older generations of workers could be opposed to using new tools and would rather use conventional techniques including 2D blueprints and physical site inspections (Li et al., 2024). Furthermore, managers and engineers must go through intensive training to apply XR properly, which increases the adoption time and expenses.

5. **Cybersecurity and Data Privacy Risks:**
As remote collaboration tools and cloud-based BIM models find increasing use, cybersecurity risks and data privacy issues become more apparent. Construction projects abound in sensitive architectural and engineering designs; hence, illegal access to XR-enabled systems might lead to intellectual property theft, data breaches, or even cyberattacks on critical infrastructure (Fu & Liu, 2018). While many companies lack the required cybersecurity systems, ensuring safe data transmission, encrypted storage, and multi-layer authentication is vital.

6. **Limited Standardization and Regulations:**
XR tools differ from other building technologies in that they lack generally accepted industry standards for deployment, which makes it challenging to produce interoperable solutions that apply across several projects and software environments. Further complicating the integration of XR into mainstream building management is the lack of clear legislative rules addressing safety compliance, AR-assisted inspections, and virtual training (Kamat et al., 2010).

7. **Cognitive and Health Concerns:**
Extended wear of VR headsets and AR smart glasses can cause cognitive overload, motion sickness, and visual tiredness. Workers who use VR for long safety training courses or AR-assisted site inspections sometimes report headaches, vertigo, and pain (Deniz et al., 2019). Manual jobs needing hand-eye coordination can also become difficult depending on XR interfaces that might not always be ergonomically ideal for field use.

2.8.2 Transforming Artistic Expression Through AR and VR

Virtual Reality (VR) and Augmented Reality (AR) are making a lot of changes in the art world. With these tools, artists and art fans can now make and enjoy art in new ways. AR and VR are changing what art is and how it can be used. For example, you can now participate in public art and watch virtual shows. But it's not all good—there are still issues that need to be fixed.

Public installations and exhibitions have been transformed thanks to AR. Augmented public art projects, for example, can overlay dynamic digital components onto real-world locations to generate interactive events inviting audience involvement. These installations transform the conventional function of the observer into active participation in the artistic creation process. On the other hand, VR allows artists to create completely digital environments where viewers are carried into through highly immersive virtual galleries or theatrical productions. These locations not only show art but also provide visitors with multisensory experiences not feasible with traditional media (Wang et al., 2024).

Moreover, ground-breaking has been XR's inclusion in theater and performance arts. Increasingly using virtual and augmented elements, stage productions create dynamic backgrounds, real-time special effects, and interactive narratives, thus enhancing the audience's emotional and visual interaction. For example, VR theater allows viewers to examine scenes from several angles, so offering a degree of interactivity and immersion never found in conventional presentations. Various points of view provide a degree of interactivity and immersion not found in traditional presentations.

2.8.3 The Role of AR and VR in Healthcare Education

In healthcare education, augmented reality (AR) and virtual reality (VR) have changed the game by giving us new ways to solve problems that have been around for a long time. People can learn more with the help of these technologies, which create realistic training environments, engaging, and correct. AR and VR are new, but they have more potential than that. As well as adding new aspects to learning and practice, they can fill in important holes in traditional school systems.

AR overlays digital data onto physical surroundings, so improving vision during surgical operations. AR, for difficult operations, for instance, lets real-time anatomical overlays on a patient's body to help accompanying surgeons. Conversely, since VR envelops users in completely simulated environments, it is a great tool for diagnosis and surgical training. In simulations, medical interns can encounter rare or high-risk events without endangering patients. One well-known example is VR-based trauma management training, which among participants considerably enhanced decision-making speed and accuracy (Asoodar et al., 2024).

By showing demanding medical procedures and conditions through interactive images, these technologies have also improved understanding and compliance, so strengthening patient education. Furthermore, they offer dynamic, repeatable, and customizable training courses to overcome the limitations of traditional methods including cadavers.

"AR/VR/MR technologies create digital environments that closely resemble real-world features. These environments enable trainees to learn tasks safely, whether within the bounds of realism or in entirely new experiences beyond traditional constraints" (Huber et al., 2017, as cited in Asoodar et al., 2024, p. 2).

AR and VR are not only improving learning outcomes but also opening the path for a more efficient and easily available healthcare education system by helping to deepen knowledge of difficult medical concepts and support safe, hands-on practice.

2.8.4 AR and VR in Electrical Engineering Education

As in art and health education industries, electrical engineering is being taught in a new way thanks to Extended Reality. Thanks to these technologies, workers and students can link with complex systems and vague ideas through interesting experiences that change with time. Applications for AR and VR have shown great potential in guiding individuals toward a better understanding of ideas, acquisition of new abilities, and increased learning motivation. These technologies are altering more and more significant aspects of regular education as the fourth industrial revolution advances.

AR helps students see and grasp real-time functional ability of electrical circuits. AR tools—for example—allow students to build and test circuits virtually without using real components by overlaying interactive components onto physical breadboards. These tools enable students to rapidly grasp the outcomes of changing variables by computing and displaying real-time voltage, current, and resistance values. Such applications lower the cognitive load linked with conventional approaches of circuit analysis and improve understanding (Asham et al., 2023).

AR and VR can fundamentally change electrical engineering education by bringing abstract concepts more concrete, building safe environments for hands-on learning, and enhancing access for a spectrum of students. Still, overcoming technical and financial limitations will help them to be generally accepted. If they are continuously creatively merged into educational processes, AR and VR will most likely become indispensable tools in guiding the direction of engineering education.

By bringing abstract concepts more concrete, creating safe environments for hands-on learning, and improving accessibility for a diverse student body, AR and VR could transform electrical engineering education. Their general acceptance, though, depends on overcoming technical and financial constraints. AR and VR are likely to become essential tools in determining the direction of engineering education if they are constantly innovatively integrated into educational processes.

2.9 Observations and Future Directions

Particularly for projects located in difficult conditions such as mountainous terrain, the combination of Extended Reality (XR) and Building Information Modeling (BIM) shows a notable development in construction management. This thesis has explored how XR technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—when combined with BIM, improve visualization capabilities, increase accuracy in planning, and promote cooperative decision-making—improve in visualizing possibilities. These technologies not only ease challenging building operations but also help to lower traditional hazards by allowing preemptive changes during the planning and implementation phases. A scholar Deniz (2019) rates the effect of the implementation of just VR from other case studies (See Figure 5).

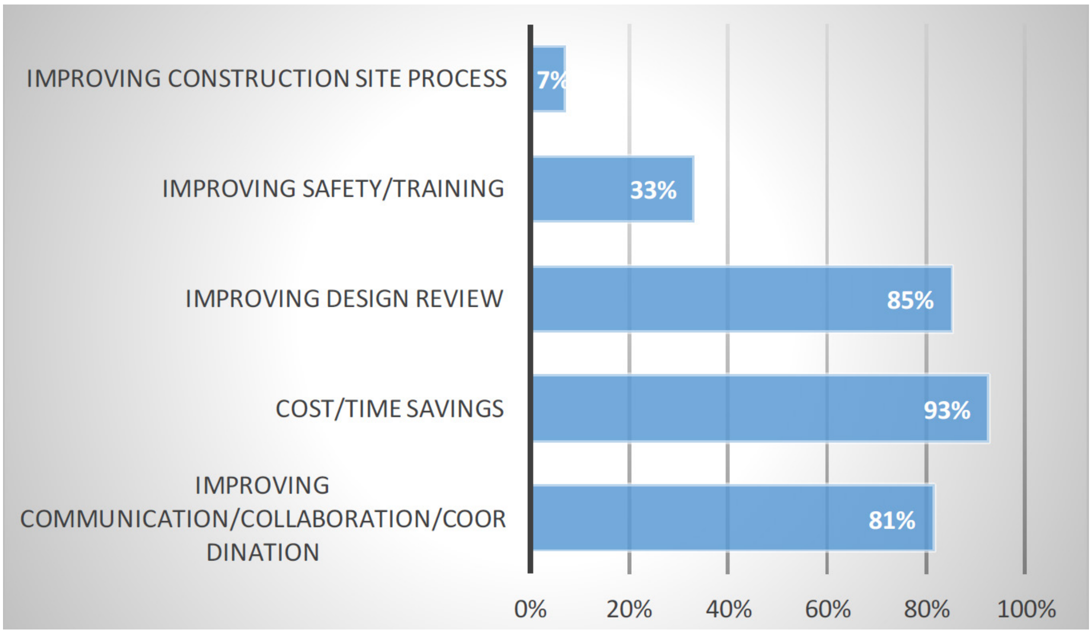


Figure 5. *Rating of enablers from case studies (Deniz, 2019)*

Analyzing extensive case studies will enable one to investigate useful applications underlining both the transforming effects and the challenges of using XR and BIM in the case study of the thesis. These examples will particularly provide insights on how these technologies might be used to overcome particular logistical and management constraints, especially in remote and difficult-to-navigate terrain. Apart from stressing the theoretical concepts discussed, the forthcoming case studies will also demonstrate the actual benefits and strategic value of XR and BIM integration in modern building technologies.

3. Case Study

Before moving on to the methodology, this chapter will provide an overview of the site location – Piane di Piedicavallo - as well as the tasks that needed to be completed for this particular case study. This chapter will explain the reasons why this particular case study is unique by elaborating on the problems that the site brings with it, which posed a challenge to the idea that was being presented in the thesis. Furthermore, in order to demonstrate the validity of the methodology, as well as as a result of the challenge, the prefab modular design and the references it makes to the concept will be articulated.

3.1 Cervo Valley

The Valle Cervo, also known as the Valle di Andorno, can be found in the province of Biella in Italy. It is situated in the north-eastern direction of the Piedmont region. The Cervo Valley is located approximately 20 kilometers to the north-south, and its elevation ranges from approximately 400 meters to 2556 meters, which is the highest point of the Monte Bo (Cima di Bo) mountain in the Alpi Biellesi. The Valley is distinguished by its mountainous topography as well as the presence of towns that are rich in history and culture, such as Piedicavallo, Rosazza, and Campiglia Cervo (see Figure 6).

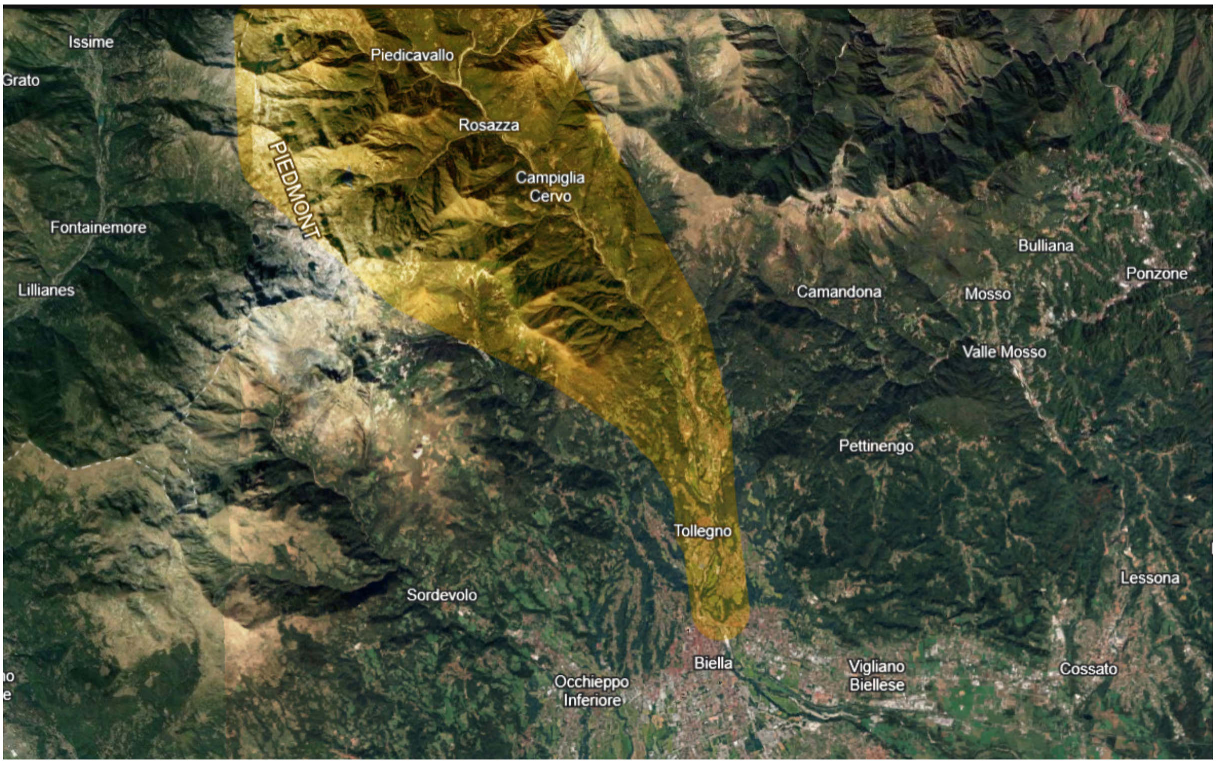


Figure 6. *Cervo Valley.*

3.1.1 Project Site

As depicted in Figure 6, the destination of the Cervo Valley is Piedicavallo, which is situated approximately 15 kilometers to the north of Biella and 70 kilometers to the northeast of Turin. There are fewer than 200 people living in this picturesque municipality that is located down the Cervo River and is surrounded by mountains. Cobblestone streets and historic buildings are among the features that have been preserved in the village's stone architecture (see Figure 7).

Figure 7. *Architecture and streets of Piedicavallo.*

On the other hand, there is still a considerable distance to travel before arriving at the ultimate destination, which is the point the thesis process began. Getting to the heart of Piedicavallo is only the beginning of the journey that leads to the destination. Accessibility for vehicles is only available up until the center, and from there, a hike of 30-40 minutes, about 1.5 km to the north-west is required. There is a pathway that is close to the river that has to be followed, and a pedestrian bridge to cross that river a bit before the final stop (see Figure 8 & 9).

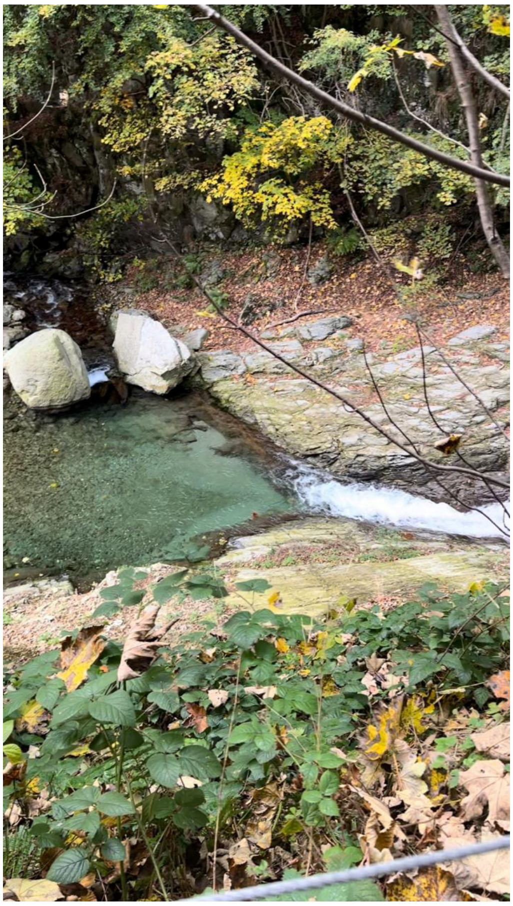
 

Figure 8 & 9. *The pathway to the site.*

A survey that was carried out by N. Rimella, who is a candidate for a doctoral degree, was referred to in order to gain an understanding of the elevation and altitude of the location. Moasure2 PRO, which will be introduced in the methodology section, was utilized by him along the path in order to scan and obtain the 3D data. The calculation was made possible by the data, which provided the number of 317 meters of height. Since it is known that Piedicavallo is approximately 1050 meters above mean sea level, the result of this calculation will be approximately 1350 meters above mean sea level (see Figure 10 & 11).

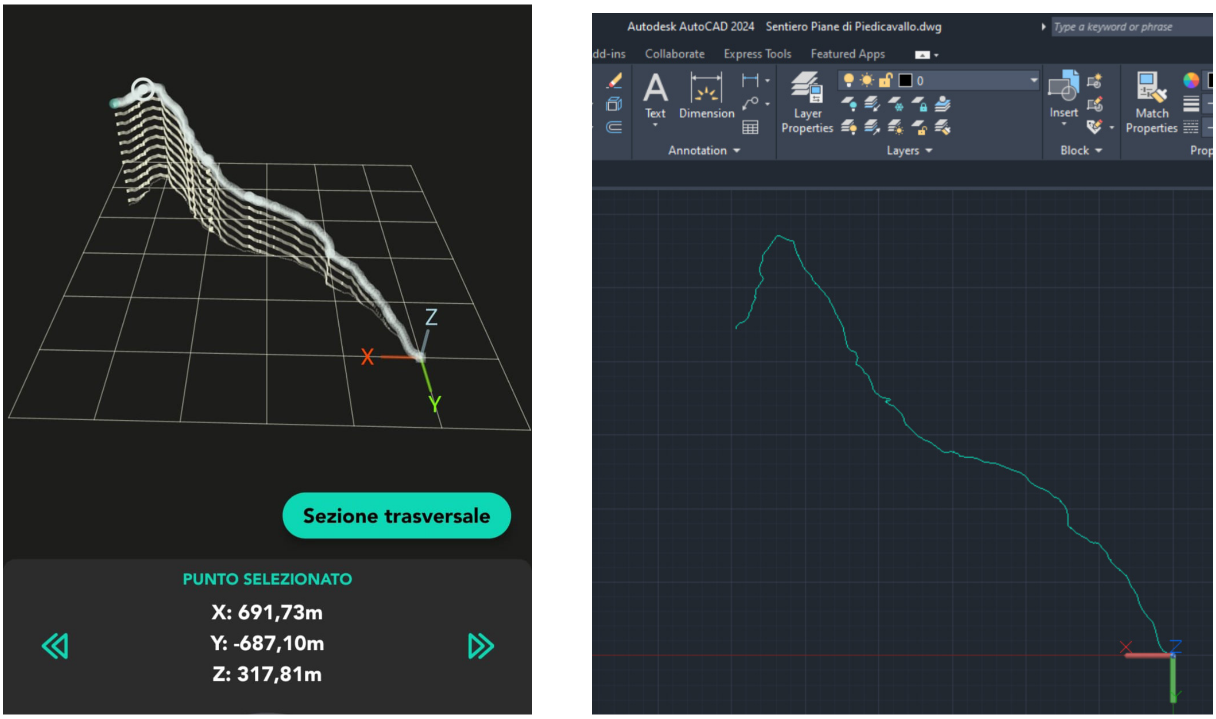


Figure 10 & 11. *Path scanning data.*

The project site for the thesis is an old mountain house that was used for residential purposes. The site and the structure are both in a very poor condition (see Figure 12). Walls are partially collapsed, and the entire area is completely overgrown with wild vegetation. There is a very steep elevation at the location of the structure, which is the reason why the northwest side of the structure is situated within the terrain (refer to Figure 22, 23 & 24 in Methodology).

Figure 12. *Site condition photo.*

3.2 Design Approach

Taking into account the location and the nature that the project site presents It was asked to design a tiny house for touristic rental purposes. Research was carried out about the architecture of the houses that are built in this type of nature and their construction processes. About this will be explained more in methodology.

The location is inaccessible to any ground vehicle, as was previously mentioned (see Figure 13). Because of this, the first thing that was considered was to minimize the amount of work that was done on the site as much as possible, both in terms of the logistics involved and the accessibility of the laborers. The utilization of the helicopter was the sole method that allowed for the management of the logistics.

Figure 13. *Accessibility overview.*

At first, it was considered to begin by tearing down the existing structure and constructing an entirely new prefabricated build. But It would be more advantageous to keep the existing structure and finish it so that it can serve as a foundation. Additionally, it would be preferable to place the new structure above the ground so that it does not come into contact with the terrain.

It was decided that a prefabricated modular solution would be the best option for the house in order to cut down on the amount of work that would be done on-site and to provide a more expedient logistics solution. In light of the fact that a helicopter that would be used to transport the modules has a maximum limit of between 500 and 600 kilograms, it was essential to reduce the weight of the structure while simultaneously increasing its durability.

The case study of Piedicavallo shows that the application of a modular prefabricated construction technique is presented in a context that is both special and demanding. Combining the remote and mountainous location with the inaccessibility of the site to ground vehicles required creative ideas for the design and project logistics. The project aims to minimize the on-site work by using a prefabricated modular system and helicopter transportation, so guaranteeing the structural integrity and sustainability of the construction at the same time. Retaining and finishing the current structure as a basis will help to further support the viability of the project. Two advantages of this method are preservation of the historical character of the site and less environmental impact. These difficulties and strategic choices prepare the ground for the method, which will be the venue for the elaboration on technical implementation and validation of the suggested approach in more depth.

4. Methodology

This study applied a methodical approach combining data collecting, design development, modeling, construction management simulation, and extended reality (XR) applications (see Figure 14). Developing a lightweight, prefabricated modular house on mountainous terrain depends on accurate terrain data, thus the process started with a precise site survey. Inspired by abroad prefabrication methods, a conceptual design started to follow the survey. Autodesk Revit was used in the modeling stage to create phase of construction, terrain organization, and point cloud data combined. Autodesk Navis works efficiently by using a work breakdown structure (WBS), so supporting construction management simulation with animations and Gantt charts. XR applications were developed last as an augmented reality (AR) simulation showing building phases in real-world surroundings, a virtual reality (VR) model for immersive design exploration, and mixed reality (MR) testing using Magic Leap 2 investigating interactive visualization possibilities. This method guaranteed a whole digital workflow, so enhancing modular building in demanding surroundings planning, visualization, and construction. Inspired by abroad prefabrication methods, a conceptual design started to follow the survey. Autodesk Revit was used in the modeling stage to create phase of construction, terrain organization, and point cloud data combined. Autodesk Navis works efficiently by using a work breakdown structure (WBS), so supporting construction management simulation with animations and Gantt charts. XR applications were developed last as an augmented reality (AR) simulation showing building phases in real-world surroundings, a virtual reality (VR) model for immersive design exploration, and mixed reality (MR) testing using Magic Leap 2 investigating interactive visualization possibilities. This approach guaranteed a whole digital workflow, so improving modular building in demanding surroundings planning, visualizing, and construction.

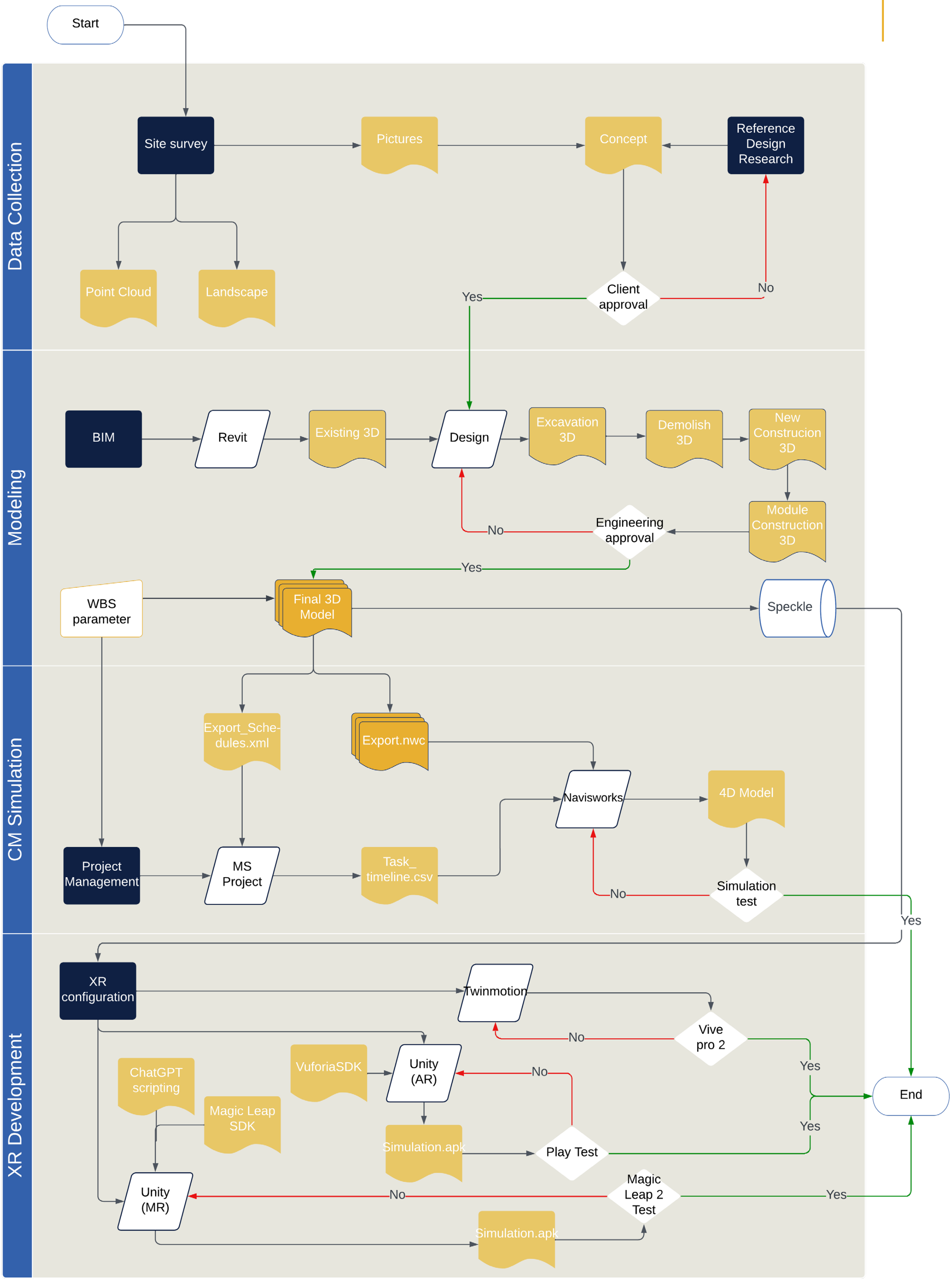


Figure 14. *Methodology workflow scheme.*

4.1 Data Collection

To ensure that the process of making a project is carried out in an effective manner, it is essential to begin with the collection of quality data. In light of the fact that the case study for the thesis is comprised of mountainous terrain, it was absolutely necessary to conduct a very precise survey during the very first and only visit to the location. It was not until after the survey that a design concept could be presented to a client for further consideration.

4.1.1 Design Concept

It was necessary to begin with the conceptual part before moving on to the modeling phase after the survey had been completed. Due to the fact that it is not possible to reach the location by any ground vehicles, portable and lightweight architectural concepts were required to be conceived of in order to fulfill the request to design a tiny house for the purpose of providing touristic rentals. After beginning with local (Italy) solutions, the search for references for the design has progressed to include global responses. The attention of these searches was drawn to the solutions that two architectural companies offered for the structure, the materials, and the logistics. **LEAPfactory** , an Italian company (See Figure15), and Fiction Factrory, a Dutch company (See Figure16), are the two companies that have mastered and experienced in providing housing solutions that are portable anywhere, lite structured, prefabricated, modular, and most importantly, sustainable.

Figure 15. Chamois 3 – LeapHome Frame – 2023. *Source:* Leapfactory. (n.d.). *Retrieved from* https://www.leapfactory.it/.

Figure 16. Wikkelhouse. *Source:* Fiction Factory. (n.d.). *Retrieved from* https://wikkelhouse.com/#.

4.1.2 Survey

In order to complete the survey, specialized instruments were utilized. As was mentioned earlier, it was necessary to bring light tools in order to facilitate easier movement. This was due to the fact that the site was difficult to access and was covered in a densely populated area of wild plants. In order to accomplish this, the **LIDAR** feature of the **iPhone 14 Pro**, along with the **Polycam** application, and the **Moasure 2** PRO, along with its **Moasure** application, were utilized during the process.

A motion-based measuring tool, Moasure is the first of its kind in the world. All of the high-performance inertial sensors that are used in its construction are crammed into a device that is small enough to fit in the palm of your hand. Moasure can track how users are moving it in three-dimensional space when it is equipped with inertial motion sensors. Every second, the device performs a calculation that determines how far and in which direction it is moved (See Figure17). This calculation is performed hundreds of times. While measuring the app will automatically draw the 3D measurement in real time. With the help of this device it was possible to get a precise 2D (see Figure 18) and 3D (see Figure 19) data of the terrain. These models were exported as DWG files for the modeling phase.

Figure 17. *Photo of **m**easuring with Moasure on the site*

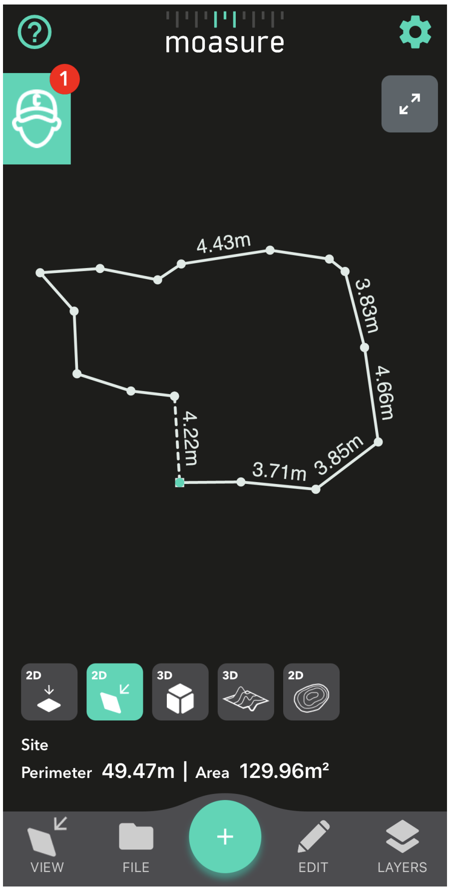


Figure 18. *Site perimeter.*

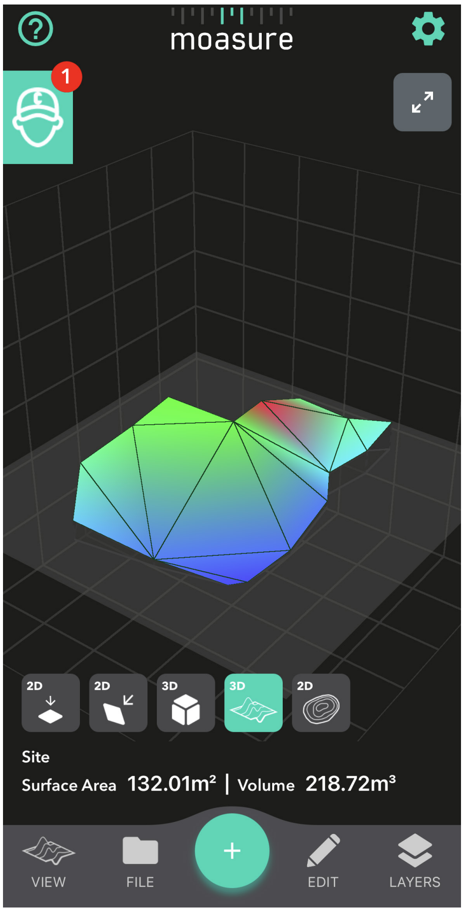


Figure19. *3D model.*

In the subsequent step, the remaining structure of the site was scanned with the assistance of the Polycam in order to acquire a three-dimensional model as well as a point cloud. Despite the fact that the ground on the site was uneven and in a particularly poor condition, it was possible to scan about 70% of the structure (see Figure 20), which was sufficient to proceed with the modeling phase. As a result of the free trial, the scanning product was exported in each and every format that was accessible within the application. This allowed for its use in all software in the future. As shown in Figure 21.

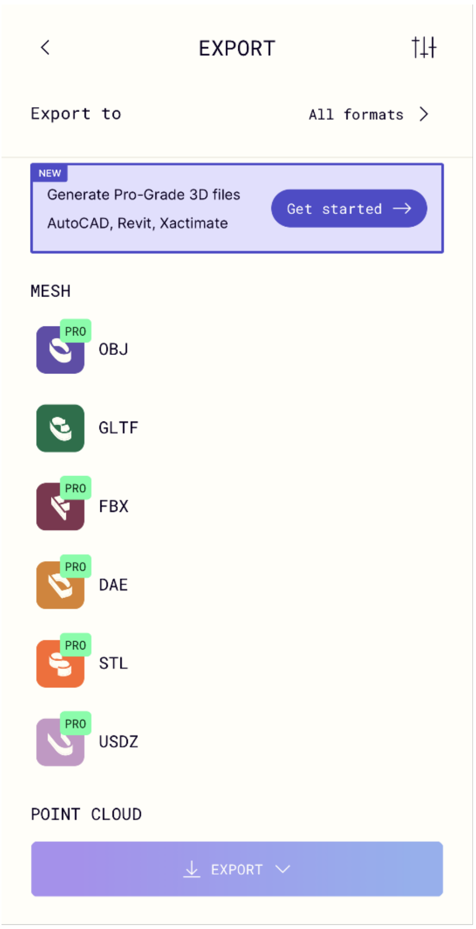


Figure 20. *Preview of Polycam scanning.*

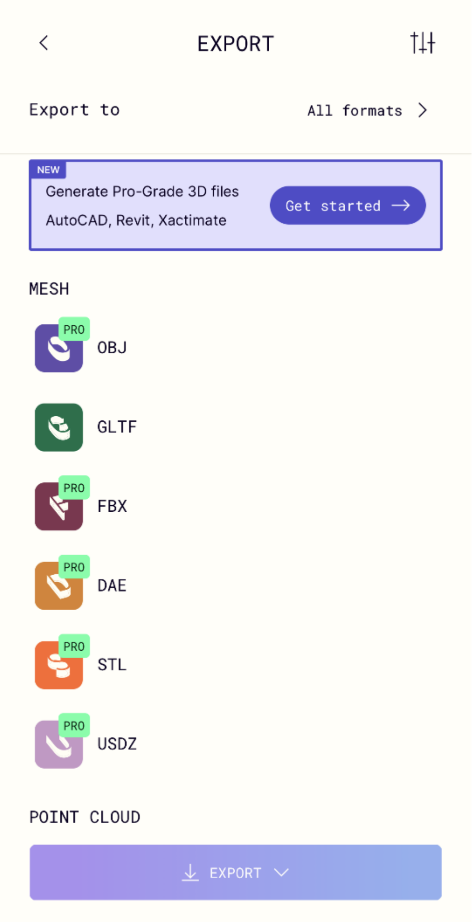


Figure21. *Some of the export options of Polycam.*

Following the completion of the survey, a few photographs were taken in order to gain a deeper comprehension of the location, its current state, and to move forward with a concept for the design. (See Figure 22, 23 & 24)

Figure 22. *Photo 1.*

Figure 23. *Photo 2.*

Figure 24. *Photo 3.*

4.2 Modeling

Modeling steps:

1. Terrain model creation
2. Pointcloud import
3. Existing phase
4. Excavation phase
5. Demolish phase
6. Construction phase
7. Module phase
8. WBS

1. Following the beginning of the modeling phase, which was based on the collection of data, **Autodesk Revit 2025** was utilized in order to achieve satisfactory results. To begin, for the purpose of having a more organized and realistic workflow for the subsequent steps, *Phases (Existing, Excavation, Demolish, New Construction, & Module Construction)* were created in *Manage tab > Phases* (see Figure 25).

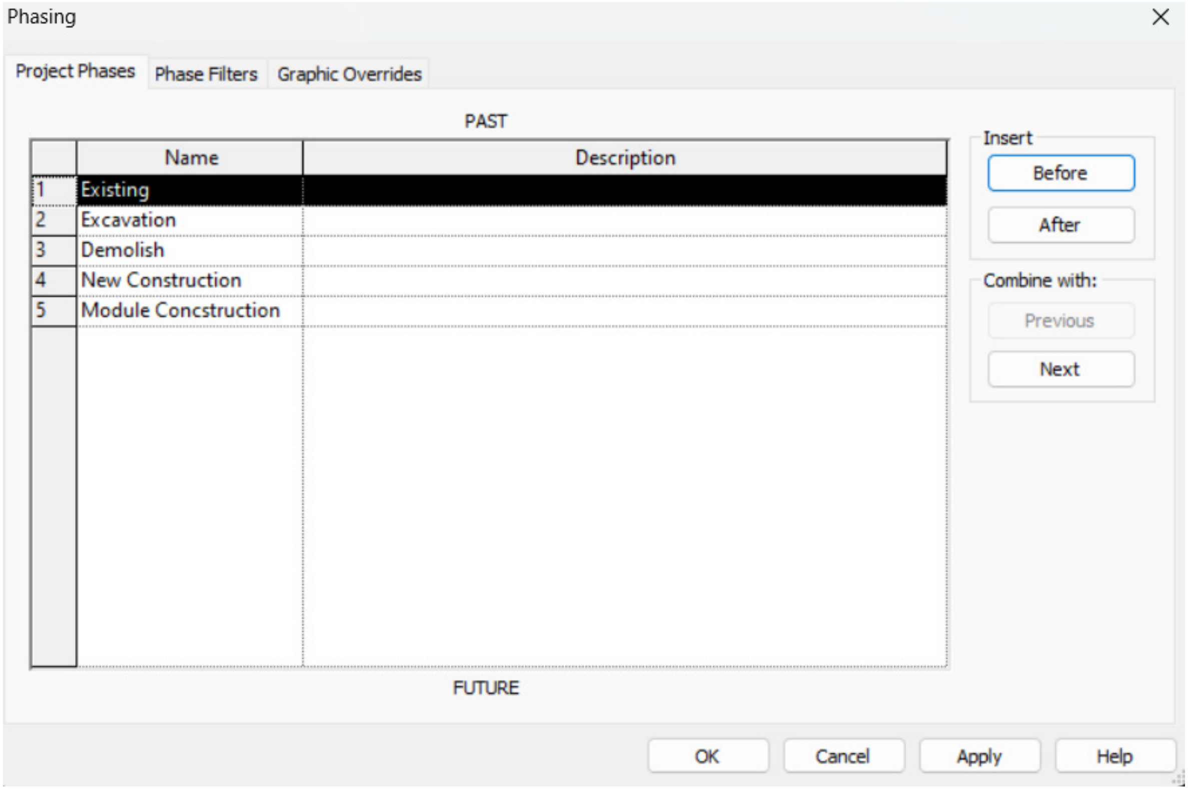


Figure25. Creating *phases*

The next step was to proceed with the creation of a three-dimensional model of the existing site. When it came to the modeling of the landscape, the terrain model that was obtained through the use of Measure was not sufficient in terms of dimensions. Therefore, a more extensive DWG terrain model was downloaded from the **CADMAPPER** website. Revit was used to import both of them, and their respective 3D models were created, as can be seen in. First, selecting *Toposolid* in Massing & Site Tab, then selecting *Create from import*, and finally selecting *Create from CAD*. At last, two models were combined into one (see Figure 26).

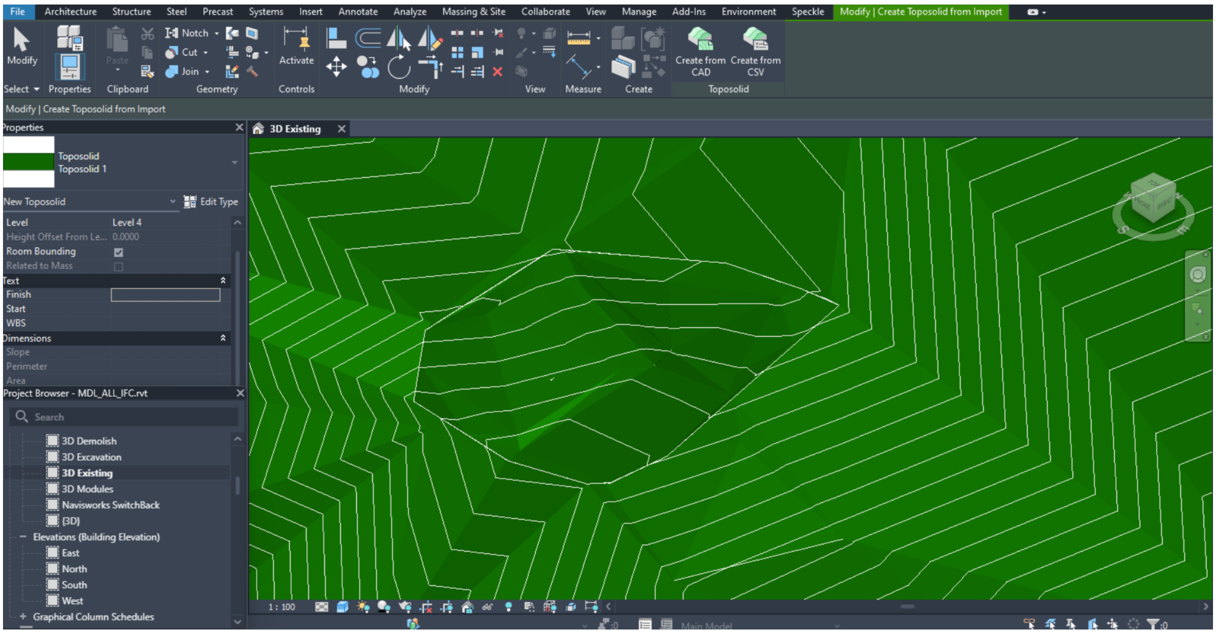


Figure 26. *Creating toposolid.*

2. Following the completion of the terrain, it was necessary to import a point cloud. In order to accomplish this, it was necessary to select *Point Cloud* from the Insert Tab; however, the importation of the file was only feasible if it was in **RCP** or **RCS** format. Through the utilization of **Autodesk ReCap 2025**, the **XYZ** file format was imported and exported from as RCS (see Figure 27). The point cloud could not be imported into Revit until after that (see Figure 28).

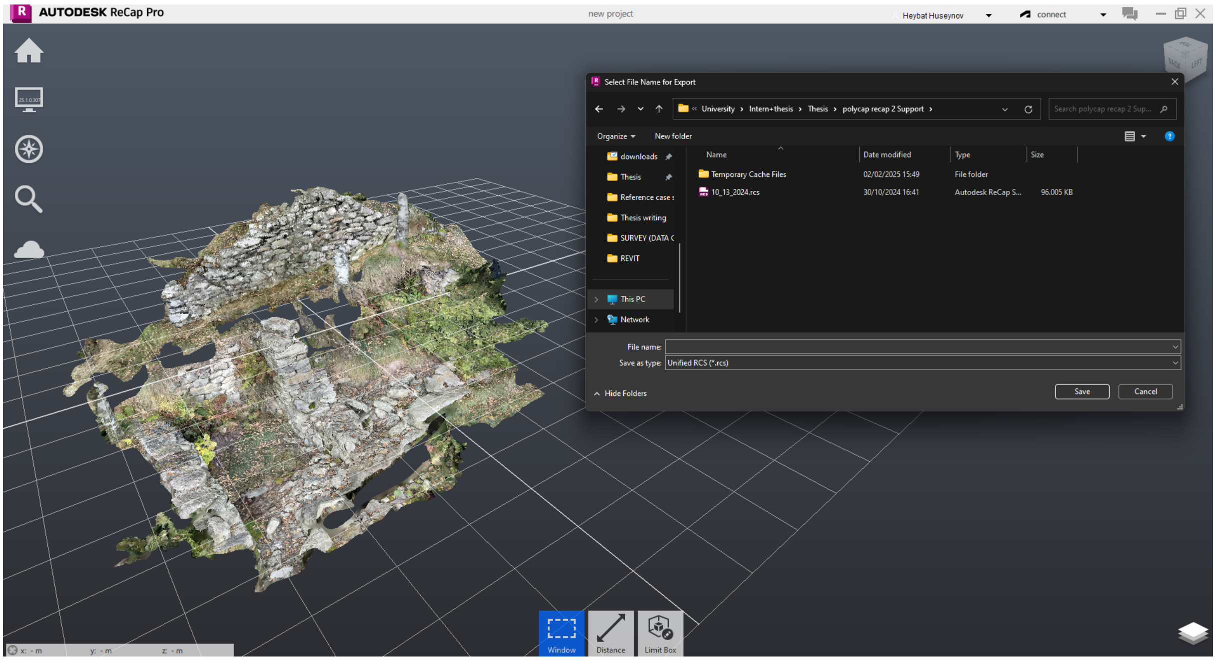


Figure 27. *ReCap Export.*

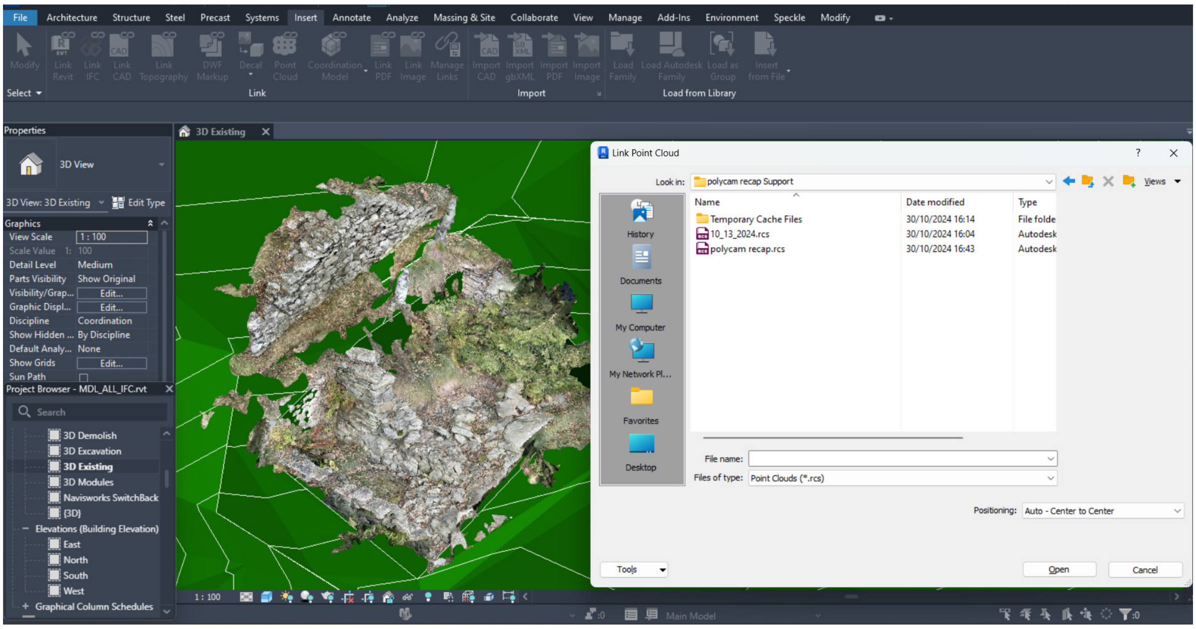


Figure 28. *Importing Point Cloud in Revit.*

3. Following the importation of all the data that was required for the modeling process, the walls of the existing structure were created by positioning them in accordance with the point cloud. Subsequently, the walls were shaped using the *Edit Profile* tool in the same manner that they appear in the point cloud (see Figure 29)

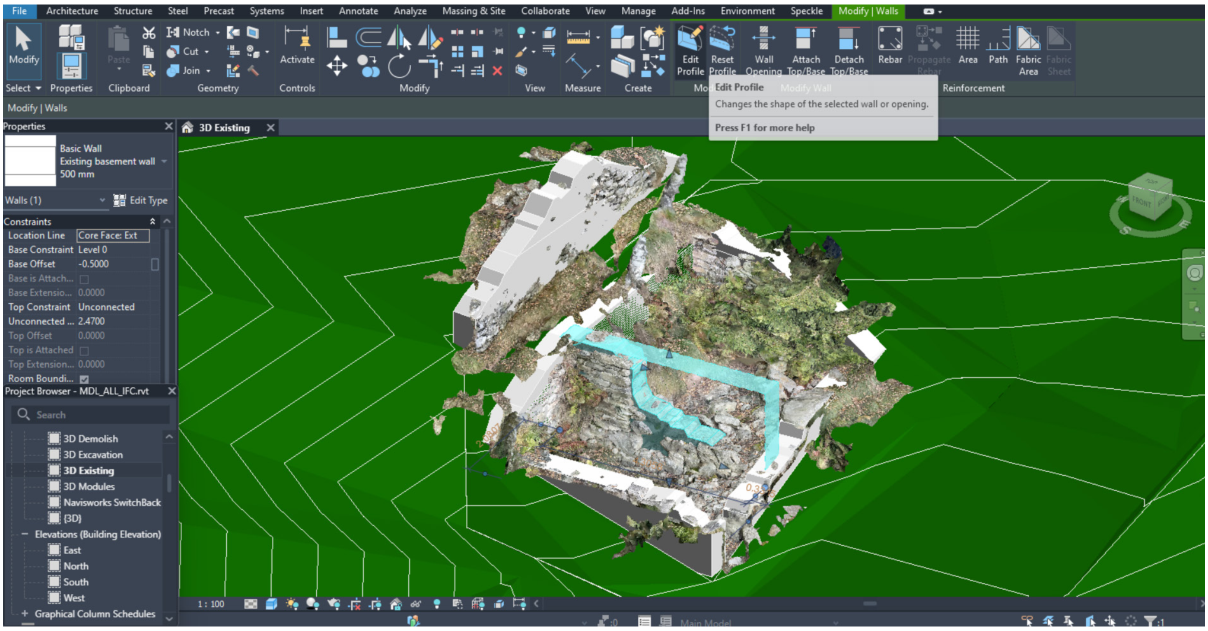


Figure 29. *Editing walls.*

The existing 3D model of the site can be finished once all of these things have been completed, and it can also be surrounded by a safety fence so that further work can be done (see Figure 30).

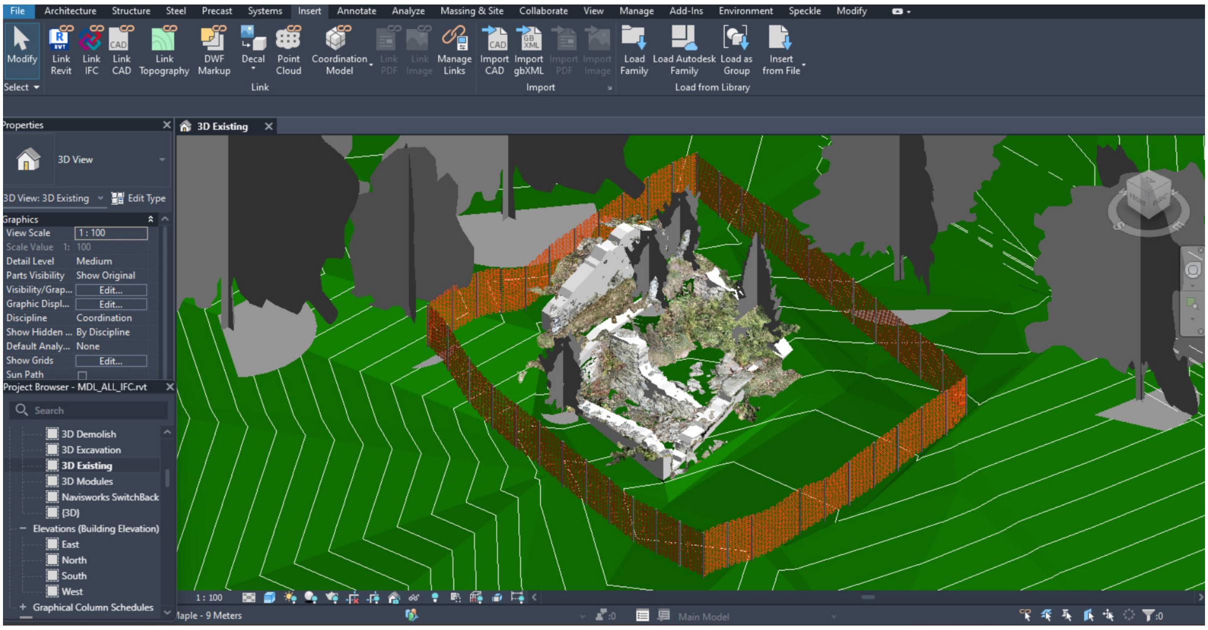


Figure 30. *Completing existing phase 3D.*

Following the completion of the existing phase, all of the subsequent phases were developed. Modifying or creating the objects in accordance with their phases of construction, which can be managed through the Phasing section of the Properties menu, was necessary in order to change the phase. The wall that has been chosen is existing (see Figure 31) and will be removed after the “Demolish” phase (see Figure 33 in demolish phase).

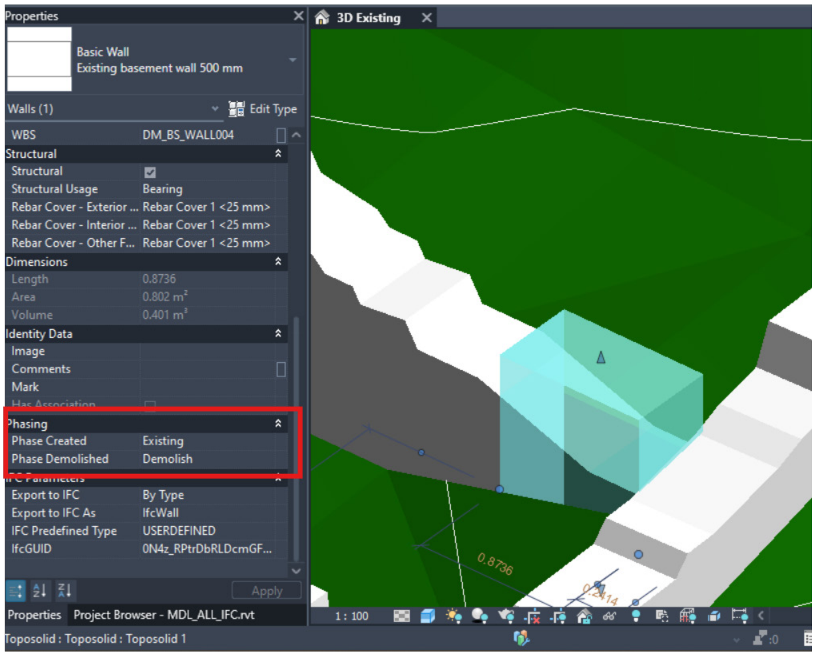


Figure 31. *Object's phasing property.*

The term "excavation phase" refers not only to the process of excavating the terrain, but also to the process of clearing the environment of any wild vegetation. A new toposolid was developed in accordance with the design concept in order to excavate the countryside. And by clicking on the terrain that needed to be excavated, the *Excavate* in Modify| Toposolid Tab (see Figure 32) is activated, and finally, the excavation is carried out by clicking on the new terrain.

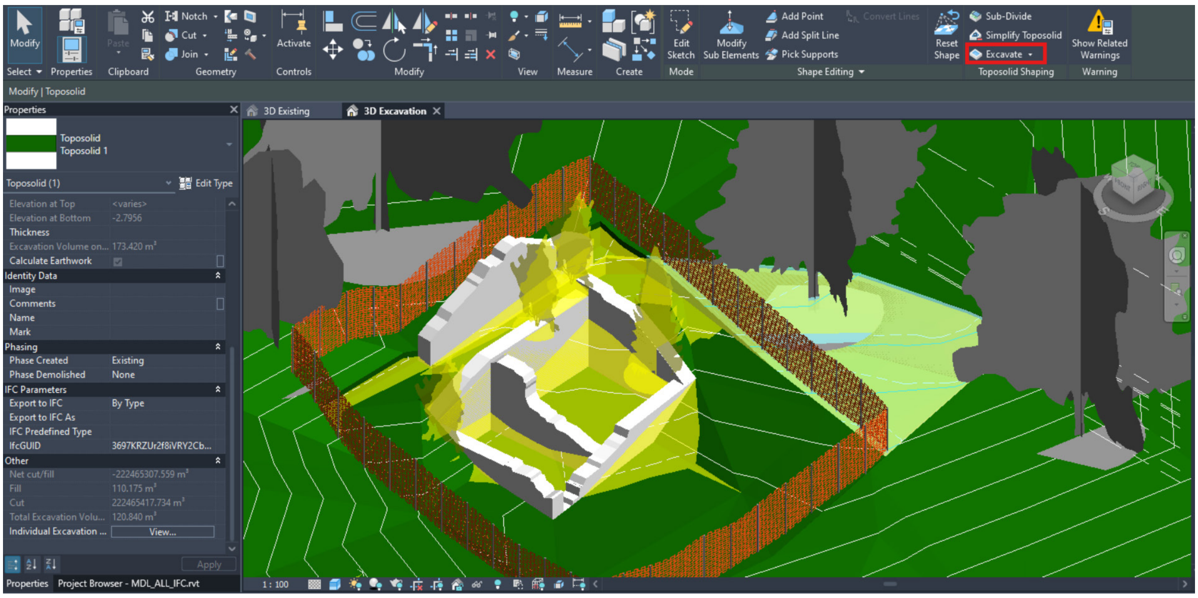


Figure 32. *Excavate tool.*

5. The demolition phase began with the creation of openings. Additionally, it was determined whether the top of the walls was higher than the height of the walls that had been decided upon for the design to be demolished. Additionally, a stone element was included, which is depicted in red in Figure 33, in order to illustrate the locations where stones that have been demolished can be placed and to symbolize their utilization in the construction of the new walls.

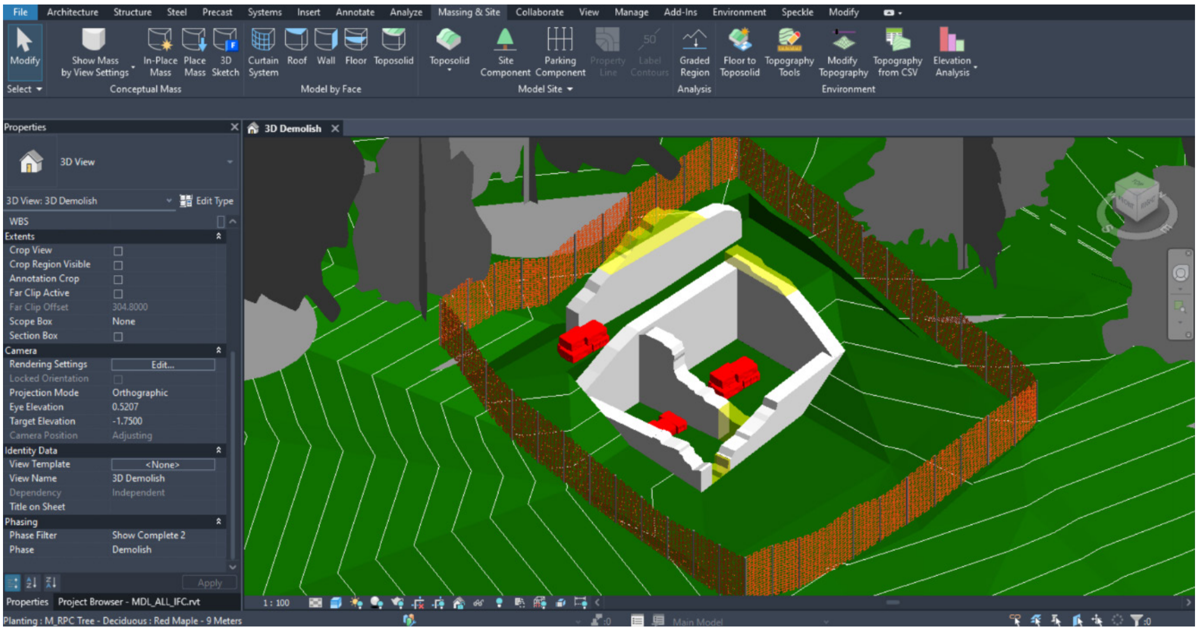


Figure 33. Demolish phase.

6. As a result of all those stages During the construction phase, the components that will be constructed on the site were discussed. There are on-site works that necessitated the addition of a separate phase prior to the final phase of the construction, which is the Module placing phase. These works include the construction of new walls on top of the existing ones, the extension of the protection wall, the creation of a new level on the terrain for improved accessibility to the house, and the provision of vertical connections (see Figure 34).

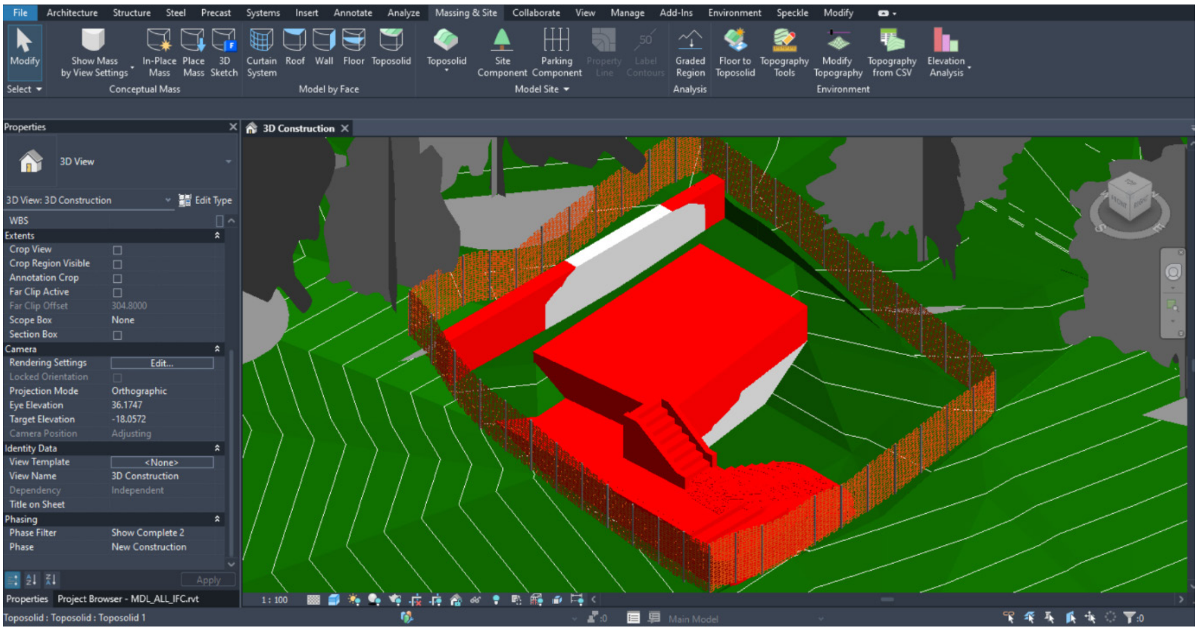


Figure34. *Construction phase.*

7. The final step and phase of the modeling process consisted of modeling a prefabricated modular house that was sitting on beams that served as the connection to the foundation or basement and as railings to place the modules while they were being mounted (see Figure 35).

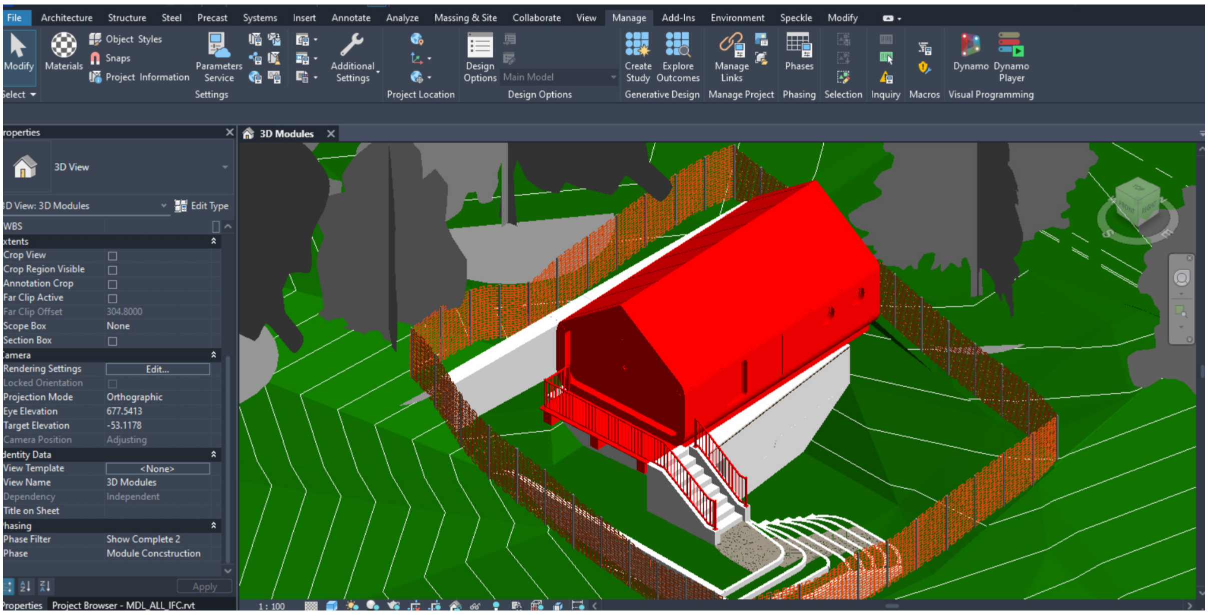


Figure 35. *Module placing phase.*

The prefabricated, lightweight, readily transportable pieces of modular housing make up their system. Every module is built using a mix of robust such as plywood caskets and natural insulation materials that guarantee structural integrity while keeping a low total weight. The design lets one be flexible in configuration, so allowing customizing depending on the need of the user.

Given each individual segment weights a maximum of about **500 kg**, it is feasible to quickly move and put together several units. Whereas the first and last modules are rather thinner, measuring **30 cm** in depth, a standard module has gross dimensions of **3.6 meters** in height, **4.6 meters in width**, and **1.2 meters** in depth. Comprising **8 modules**, the construction links effortlessly to create a stable and insulated living environment (see Figure 36 & 37).

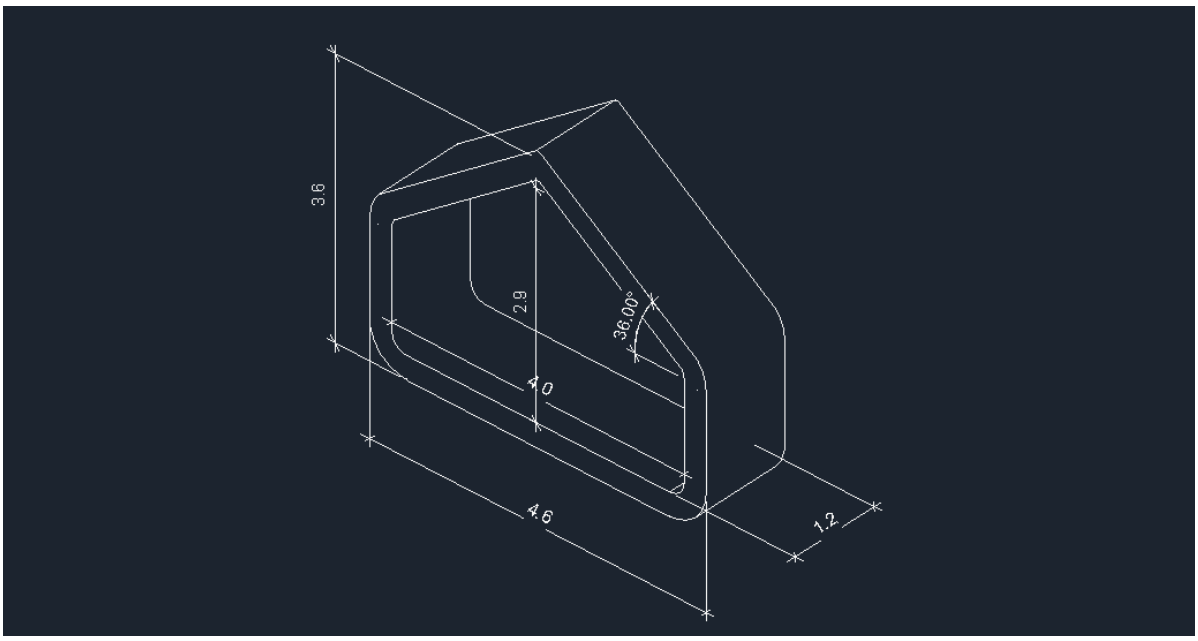


Figure 36. *Technical view of one module.*

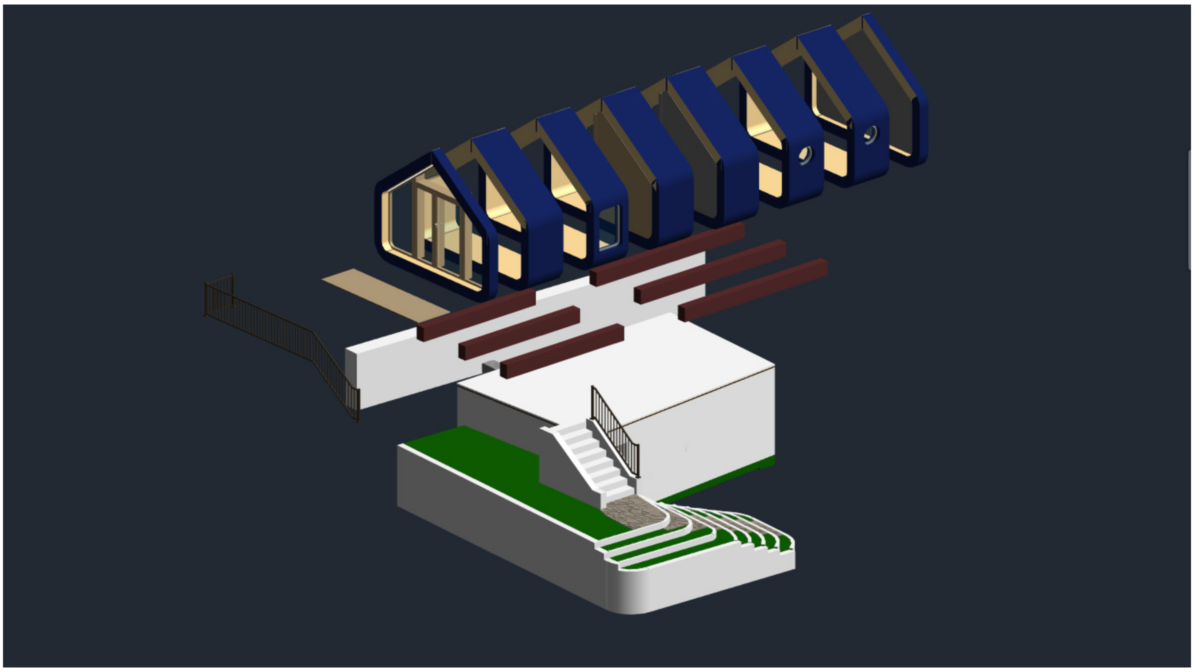


Figure 37. *Exploded to view of the modules.*

Sustainable aluminium plates were thought to shield the construction from outside natural influences, so improving durability and weather resistance. The inside stays simple yet useful in design. The system is ideal for sites with logistical restrictions, such remote areas or challenging-to-access terrain, given its lightweight construction.

Initial modeling of the module's shape was accomplished through the utilization of *In-Place Mass* in Massing & Site Tab. After that, again in the Massing & Site Tab Roof Wall and Floor tools were utilized once more in order to create entities in accordance with the requirement by clicking on the mass and selecting it (see Figure38).

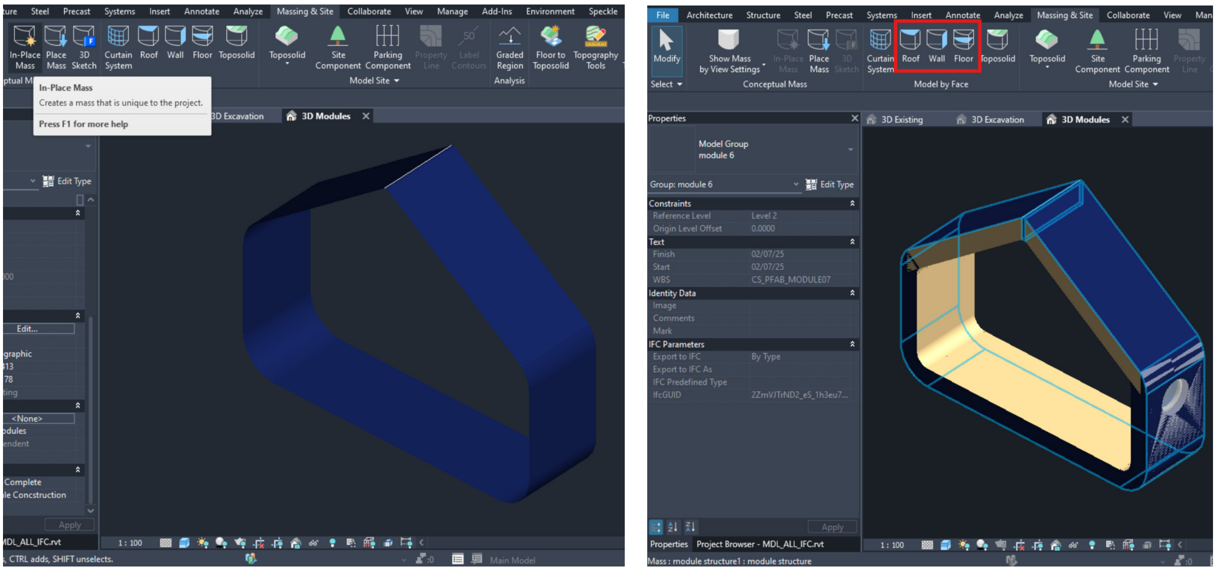


Figure 38. *Modeling the module.*

8. Following the completion of the final step of the modeling process, it was time to move on to the next step, which was Construction Management. However, prior to beginning, as was mentioned earlier, the WBS parameter needed to be created in order to manage the CM process in a more effective and efficient way. This shared parameter

was created by selecting the Manage Tab, then selecting *Shared Parameters*, finally in the window that was opened adding parameters to the group of parameters (see Figure 39).

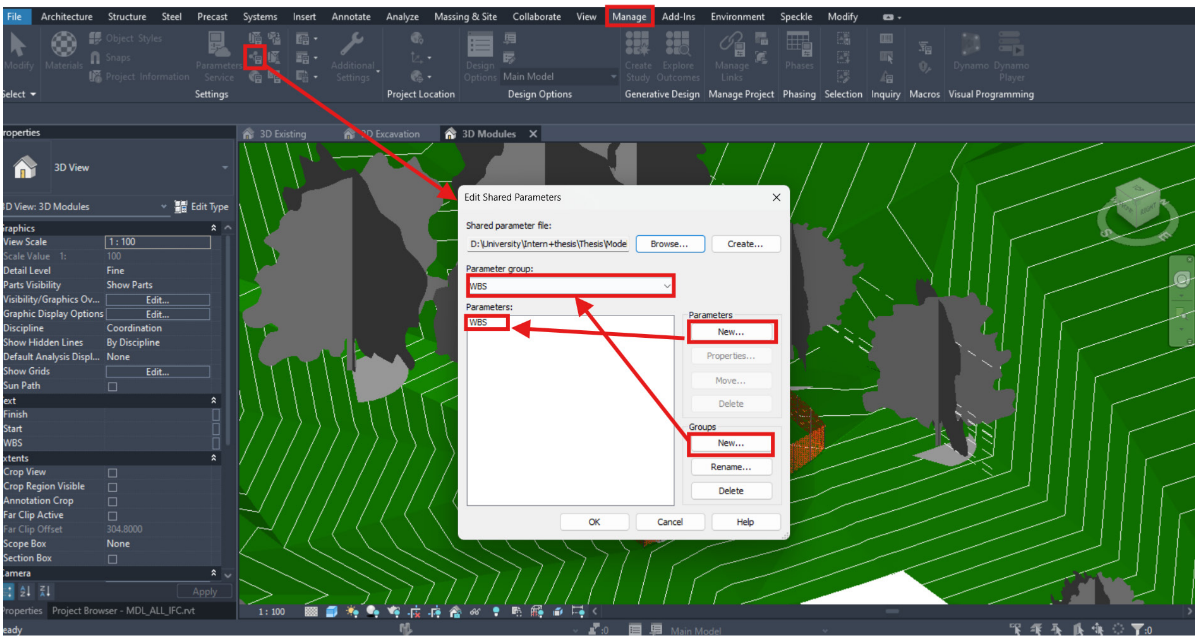


Figure 39. *Creating shared parameter.*

It was necessary to add the shared parameter to the project parameters after it had been created. This can be done by going back to the Manage Tab and selecting Project Parameters (see Figure 40). It wasn't until after that that the Properties Menu started allowing user to add WBS parameters to objects.

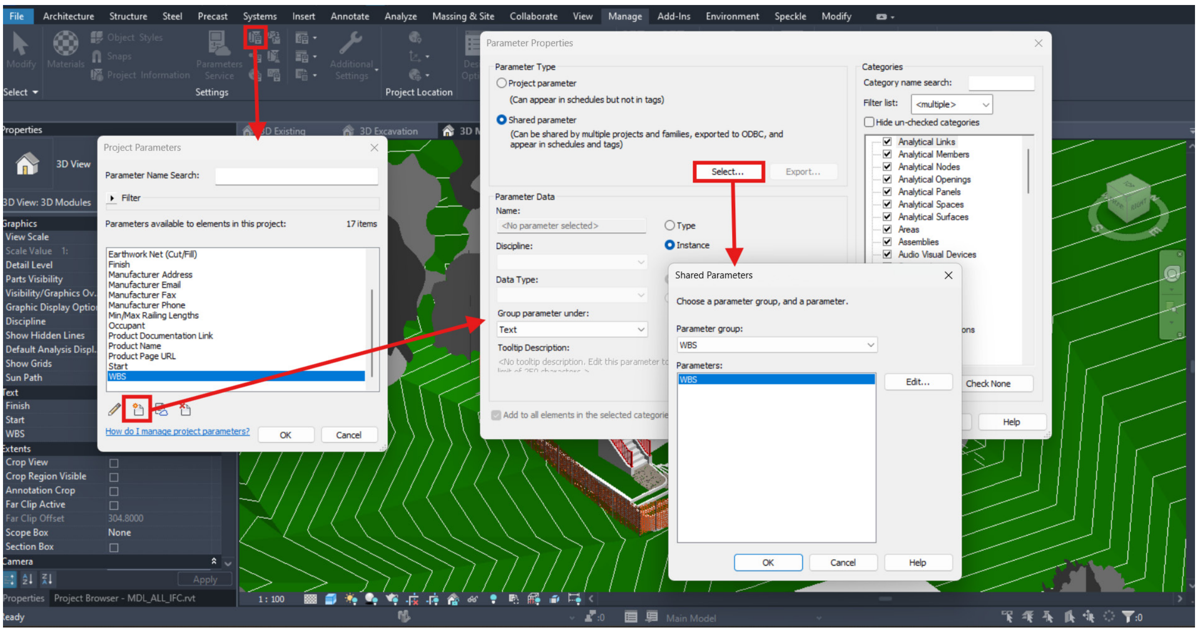


Figure 40. *Creating project parameter.*

As *A_B_Cn*, the WBS was organized into three sections. The symbol "A" denotes the phase in which an object was functioning. The symbol "B" represents the structure to which an object belongs. The final component, "Cn", is the type of the object as well as its counted number. In accordance with what is depicted in Figure 41, the terms “EX” and “CS” are respectively referred to as Existing and Construction phases. The abbreviation “BS” refers to the Basement, and the third section is obviously the type of wall, which is the wall in this particular instance, and its counted number.

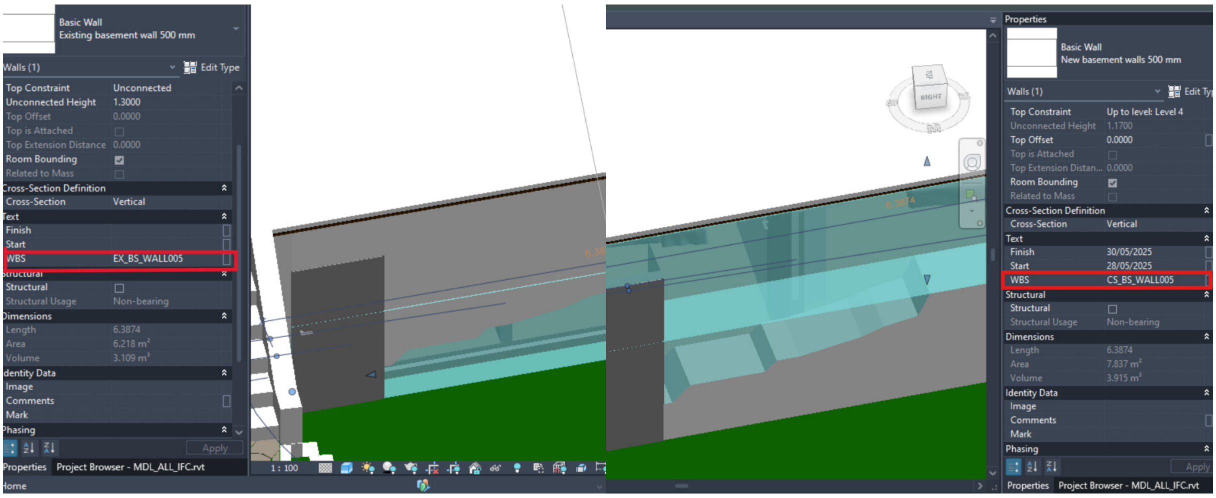
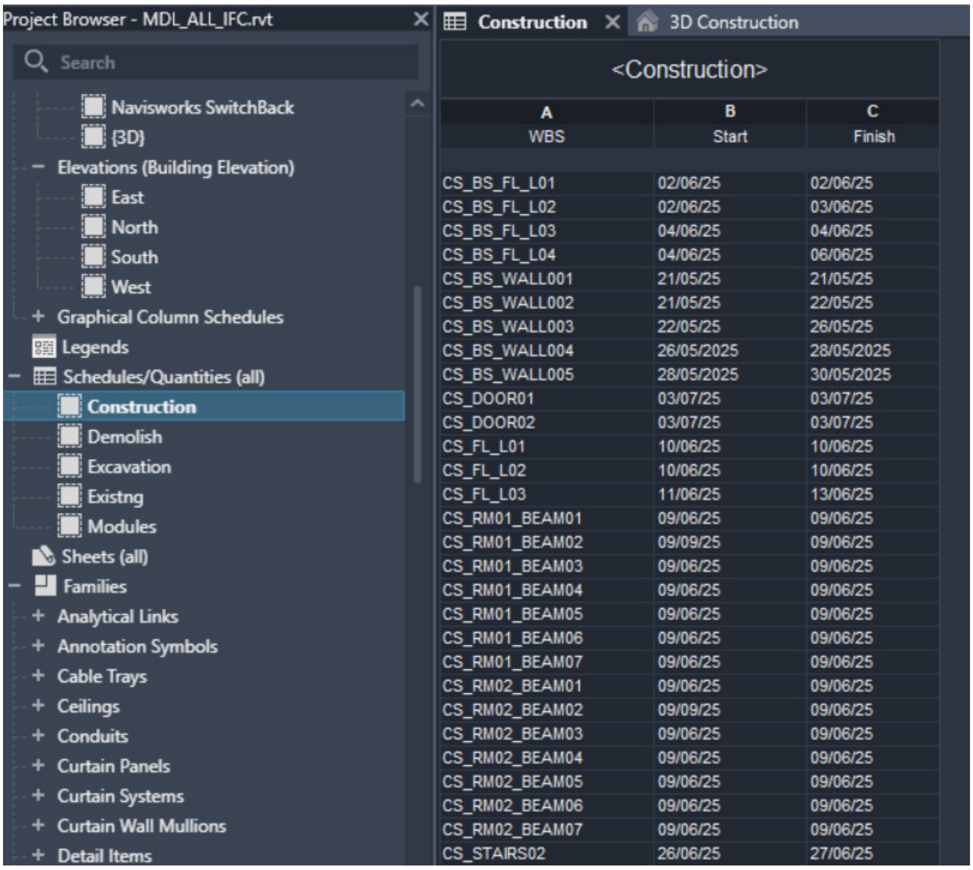


Figure 41. *Entering WBS parameter.*

Having a WBS that was structured in this manner made it much simpler to draw up schedules and to select which objects should be included in the phase schedules. Within the Revit software, the beginning and ending dates of the tasks were already incorporated for the purpose of enhancing comprehension and facilitating more effective organization (see Figure 42).



A WBS	B Start	C Finish
CS_BS_FL_L01	02/06/25	02/06/25
CS_BS_FL_L02	02/06/25	03/06/25
CS_BS_FL_L03	04/06/25	04/06/25
CS_BS_FL_L04	04/06/25	06/06/25
CS_BS_WALL001	21/05/25	21/05/25
CS_BS_WALL002	21/05/25	22/05/25
CS_BS_WALL003	22/05/25	26/05/25
CS_BS_WALL004	26/05/2025	28/05/2025
CS_BS_WALL005	28/05/2025	30/05/2025
CS_DOOR01	03/07/25	03/07/25
CS_DOOR02	03/07/25	03/07/25
CS_FL_L01	10/06/25	10/06/25
CS_FL_L02	10/06/25	10/06/25
CS_FL_L03	11/06/25	13/06/25
CS_RM01_BEAM01	09/06/25	09/06/25
CS_RM01_BEAM02	09/09/25	09/06/25
CS_RM01_BEAM03	09/06/25	09/06/25
CS_RM01_BEAM04	09/06/25	09/06/25
CS_RM01_BEAM05	09/06/25	09/06/25
CS_RM01_BEAM06	09/06/25	09/06/25
CS_RM01_BEAM07	09/06/25	09/06/25
CS_RM02_BEAM01	09/06/25	09/06/25
CS_RM02_BEAM02	09/09/25	09/06/25
CS_RM02_BEAM03	09/06/25	09/06/25
CS_RM02_BEAM04	09/06/25	09/06/25
CS_RM02_BEAM05	09/06/25	09/06/25
CS_RM02_BEAM06	09/06/25	09/06/25
CS_RM02_BEAM07	09/06/25	09/06/25
CS_STAIRS02	26/06/25	27/06/25

Figure 42. Creating schedule.

Following the creation of the schedules for each phase, the schedules were exported as CSV files and then combined with Excel in a single file in order to move forward with the Construction Management process (see Figure 43).

1	WBS	Start	Finish	Phase
2				
3	EX_BS_WALL001			Existng
4	EX_BS_WALL002			Existng
5	EX_BS_WALL003			Existng
6	EX_BS_WALL004			Existng
7	EX_BS_WALL005			Existng
8	EX_TRRN_SRRND			Existng
9	EX_TRRN_ST			Existng
10	EX_TRRN_WALL001			Existng
11	EXC_TRRN_SRND			Excavation
12	EXC_TRRN_TREE001	12/05/2025	12/05/2025	Excavation
13	EXC_TRRN_TREE002	12/05/2025	12/05/2025	Excavation
14	EXC_TRRN_TREE003	13/05/2025	13/05/2025	Excavation
15	EXC_TRRN_TREE004	13/05/2025	13/05/2025	Excavation
16	EXC_TRRN_GRND001	14/05/2025	14/05/2025	Excavation
17	EXC_TRRN_GRND002	15/05/2025	15/05/2025	Excavation
18	EXC_TRRN_ST01	16/05/2025	16/05/2025	Excavation
19	EXC_TRRN_ST02	19/05/2025	19/05/2025	Excavation
20	DM_BS_WALL003	20/05/2025	20/05/2025	Demolish
21	DM_BS_WALL004	20/05/2025	20/05/2025	Demolish
22	DM_BS_WALL005	20/05/2025	20/05/2025	Demolish
23	DM_TRRN_WALL001	20/05/2025	20/05/2025	Demolish
24	CS_BS_WALL001	21/05/2025	21/05/2025	Construction
25	CS_BS_WALL002	21/05/2025	22/05/2025	Construction

Figure 43. *Organazing in Excel.*

4.3 Construction Management Simulation

All of the components needed to be prepared before the simulation could be created, and then they were imported into **Autodesk Navisworks Manage 2025**. Immediately following the completion of the task list, it was imported into **Microsoft Project 2016**, which is where the Gantt chart was created. Employees were required to put in eight hours of work each day, forty hours per week, and workdays were from Monday to Friday. Important to note that the time and dates were assumed, and that they do not reflect any actual workflow.

A representation of the relationship between the tasks can be found in the first column of the Gantt chart. There are four types of relations in general:

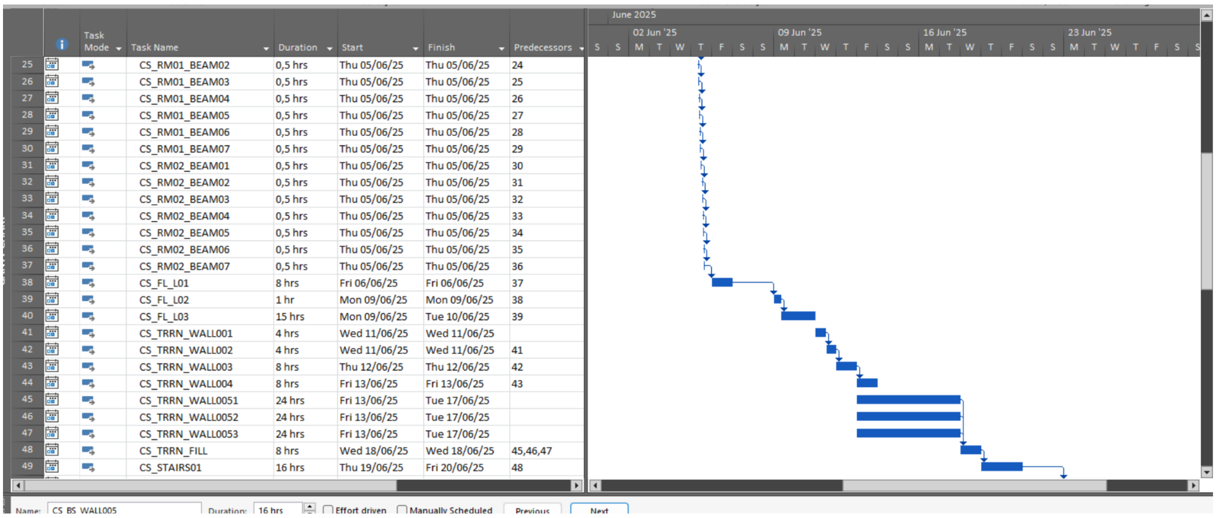
End – Start: The following activity starts when the one that came before it comes to an end. This is the more common relationship that is used.

Start – Start: A simultaneous initiation of two or more activities is taking place.

End – End: Because the final date is the connecting factor between two activities, it is possible for them to begin at different times but they must both conclude on the same date.

Start – End: When the other activity begins, the one that was chosen must come to an end.

The mode of the task is displayed in the second column, which indicates whether the task is scheduled manually or automatically. The WBS parameters that were exported from Revit are listed in the following column entitled *Task Name*. The time and date columns, which stand for the duration of the task as well as the beginning and ending dates, are located in columns 3, 4, and 5. Additionally, the "turn" of the task is represented by the *Predecessors* column, which is the final column in the table (see Figure 44).



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
25		CS_RM01_BEAM02	0,5 hrs	Thu 05/06/25	Thu 05/06/25	24
26		CS_RM01_BEAM03	0,5 hrs	Thu 05/06/25	Thu 05/06/25	25
27		CS_RM01_BEAM04	0,5 hrs	Thu 05/06/25	Thu 05/06/25	26
28		CS_RM01_BEAM05	0,5 hrs	Thu 05/06/25	Thu 05/06/25	27
29		CS_RM01_BEAM06	0,5 hrs	Thu 05/06/25	Thu 05/06/25	28
30		CS_RM01_BEAM07	0,5 hrs	Thu 05/06/25	Thu 05/06/25	29
31		CS_RM02_BEAM01	0,5 hrs	Thu 05/06/25	Thu 05/06/25	30
32		CS_RM02_BEAM02	0,5 hrs	Thu 05/06/25	Thu 05/06/25	31
33		CS_RM02_BEAM03	0,5 hrs	Thu 05/06/25	Thu 05/06/25	32
34		CS_RM02_BEAM04	0,5 hrs	Thu 05/06/25	Thu 05/06/25	33
35		CS_RM02_BEAM05	0,5 hrs	Thu 05/06/25	Thu 05/06/25	34
36		CS_RM02_BEAM06	0,5 hrs	Thu 05/06/25	Thu 05/06/25	35
37		CS_RM02_BEAM07	0,5 hrs	Thu 05/06/25	Thu 05/06/25	36
38		CS_FL_L01	8 hrs	Fri 06/06/25	Fri 06/06/25	37
39		CS_FL_L02	1 hr	Mon 09/06/25	Mon 09/06/25	38
40		CS_FL_L03	15 hrs	Mon 09/06/25	Tue 10/06/25	39
41		CS_TRRN_WALL001	4 hrs	Wed 11/06/25	Wed 11/06/25	
42		CS_TRRN_WALL002	4 hrs	Wed 11/06/25	Wed 11/06/25	41
43		CS_TRRN_WALL003	8 hrs	Thu 12/06/25	Thu 12/06/25	42
44		CS_TRRN_WALL004	8 hrs	Fri 13/06/25	Fri 13/06/25	43
45		CS_TRRN_WALL0051	24 hrs	Fri 13/06/25	Tue 17/06/25	
46		CS_TRRN_WALL0052	24 hrs	Fri 13/06/25	Tue 17/06/25	
47		CS_TRRN_WALL0053	24 hrs	Fri 13/06/25	Tue 17/06/25	
48		CS_TRRN_FILL	8 hrs	Wed 18/06/25	Wed 18/06/25	45,46,47
49		CS_STAIRS01	16 hrs	Thu 19/06/25	Fri 20/06/25	48

Figure 44. *A section from Gantt chart.*

Before beginning work in Navisworks, there was one final step that needed to be taken, and that was exporting the NWC files from Revit. In this particular instance, **Publish NWC** needed to be added in Revit. To facilitate more effective task control, each phase was exported separately.

After having all the files ready new project was created in Navisworks in NWF format. NWF files are ideal for ongoing projects with frequent updates because they index model files and store Navisworks data without embedding geometry. However, NWD files combine geometry and Navisworks-specific data into a compact, distributable format that can be viewed using Freedom without a Navisworks license. NWC files cache converted model geometry for faster loading and file conversion, not for user distribution.

By clicking on Append all NWC files were imported into the project, including excavator and helicopter geometries, as shown in Figure 45.

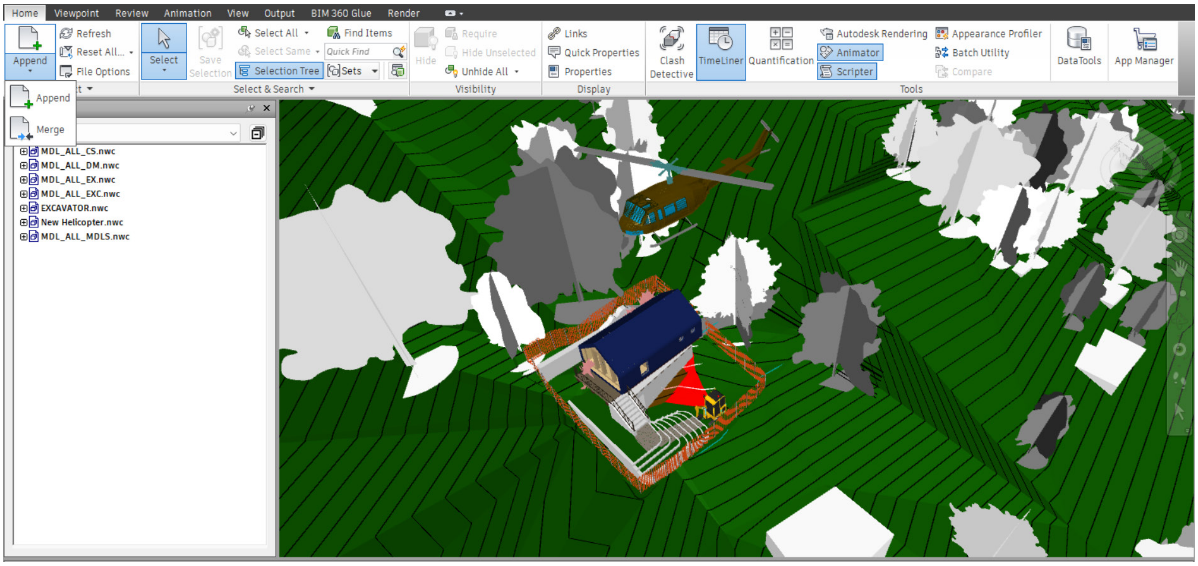


Figure 45. *Importing NWC files in Navisworks Manage.*

Following that, the task timeline file was imported by following the steps as *TimeLiner, Data Sources, Add*, and finally *Microsoft Project 2007-2013*, which enables the importation of files in the IMPP format (see Figure 46).

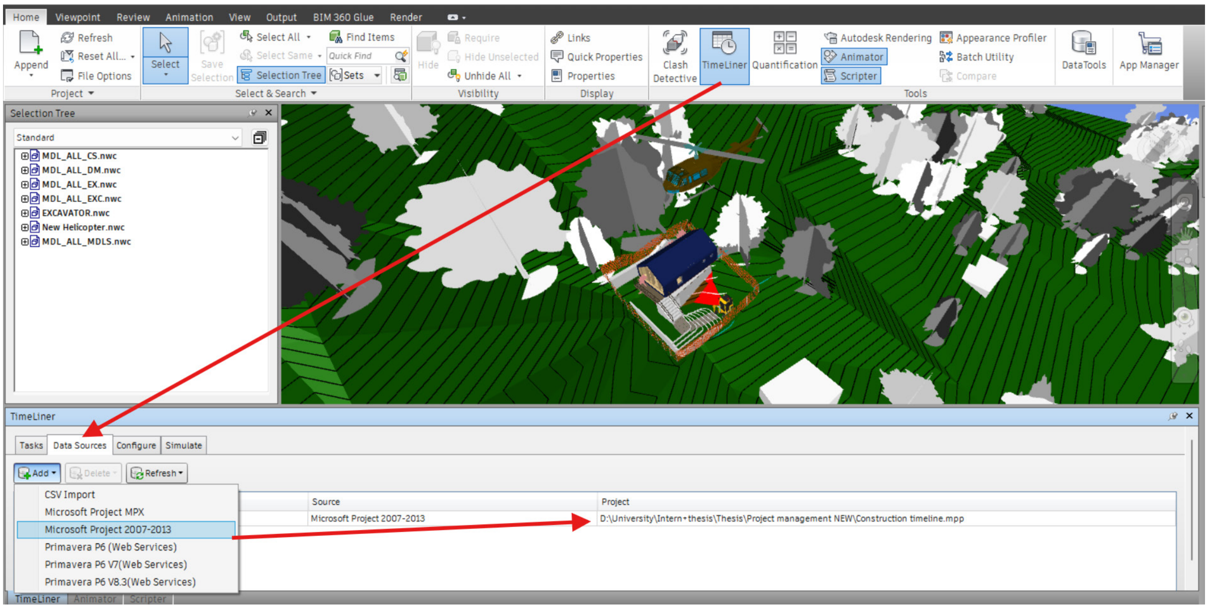


Figure 46. *Importing the task timeline.*

It was necessary to select the imported file, and then, after clicking on the *Refresh* button, then on Selected Data Sources tasks would appear in the Tasks tab (see Figure 47).

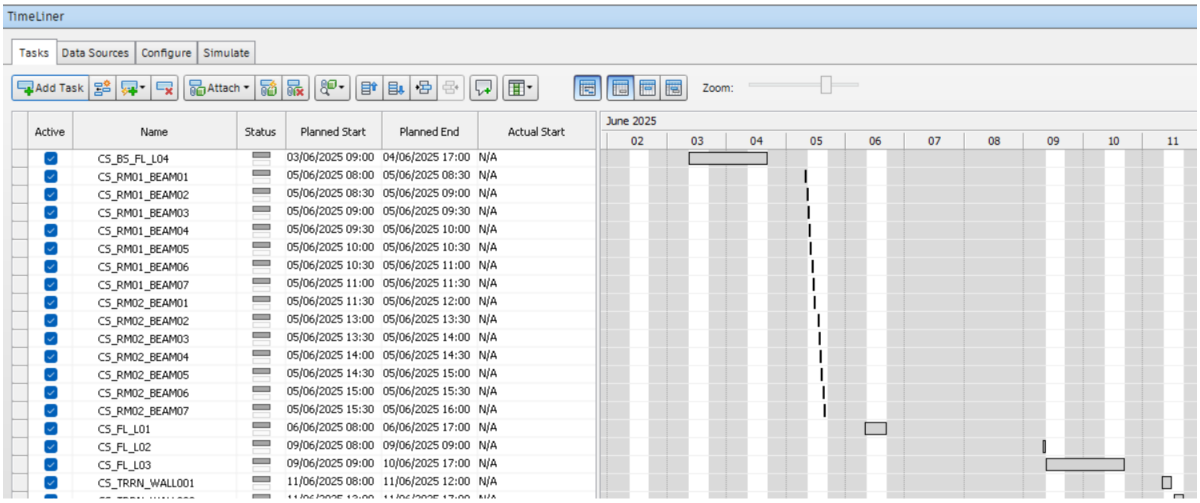


Figure 47. *Tasks in Navisworks.*

Tasks were required to be attached to their respective entities during this sept. It was at this point that the WBS played an extremely important role. When an item is selected in the *Custom* section of the *Properties* menu in Navisworks, it is possible to view the parameters that were created in Revit (see Figure 48). In order to make the process automatic, a new Rule needed to be developed. There were instances in which it was possible to set the Task name so that it matched the WBS property of the items. In order to accomplish this, *Auto-Attach Using Rules* was utilized, and a new Rule was subsequently created (see Figure 49). The final step was to simply click on the *Apply Rules* button, and the software would take care of everything else automatically (see Figure 50).

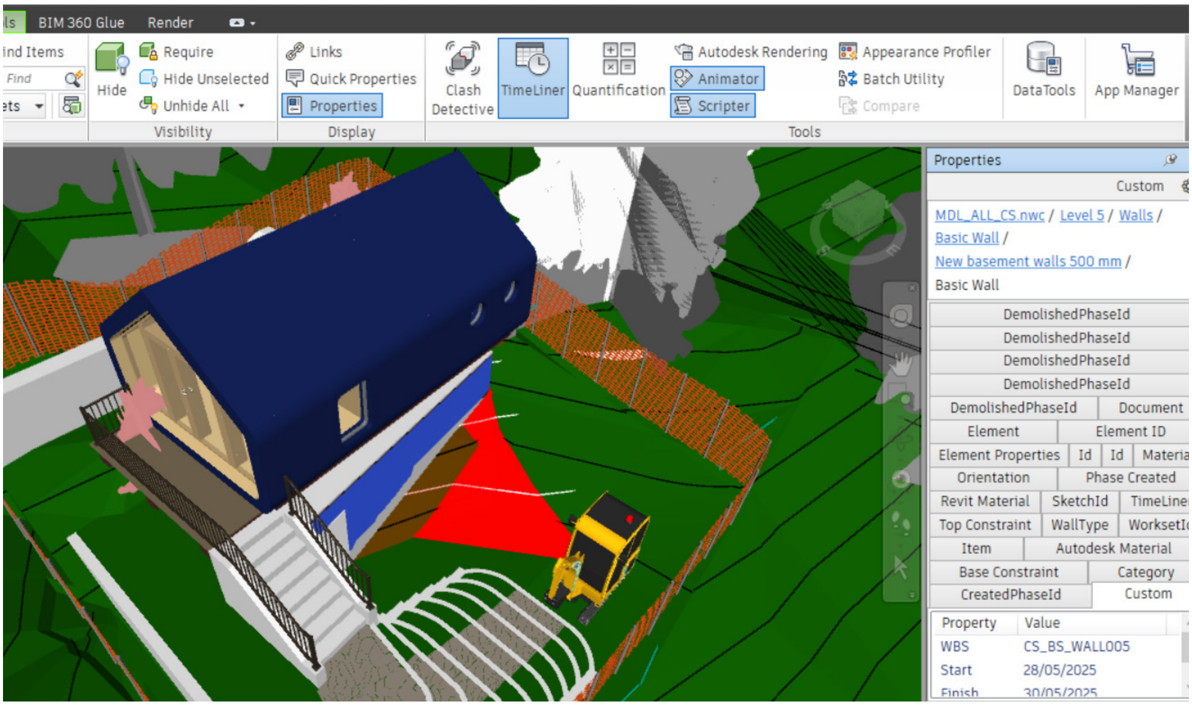


Figure 48. *Viewing WBS propery in Navisworks.*

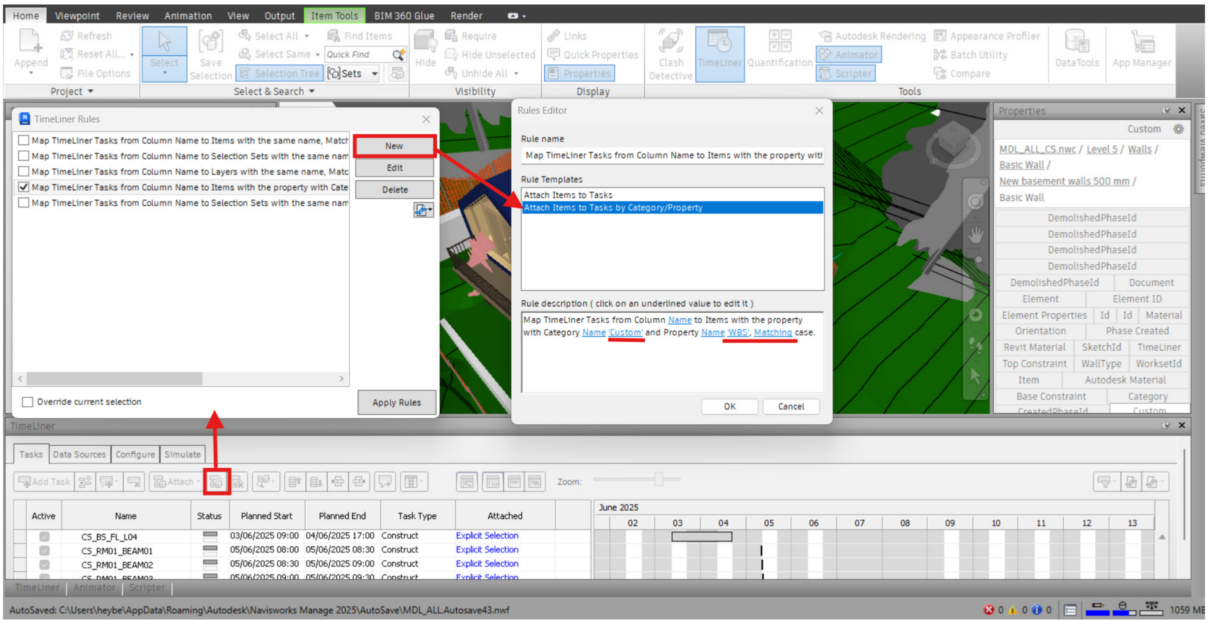


Figure 49. *Creating new Rule.*

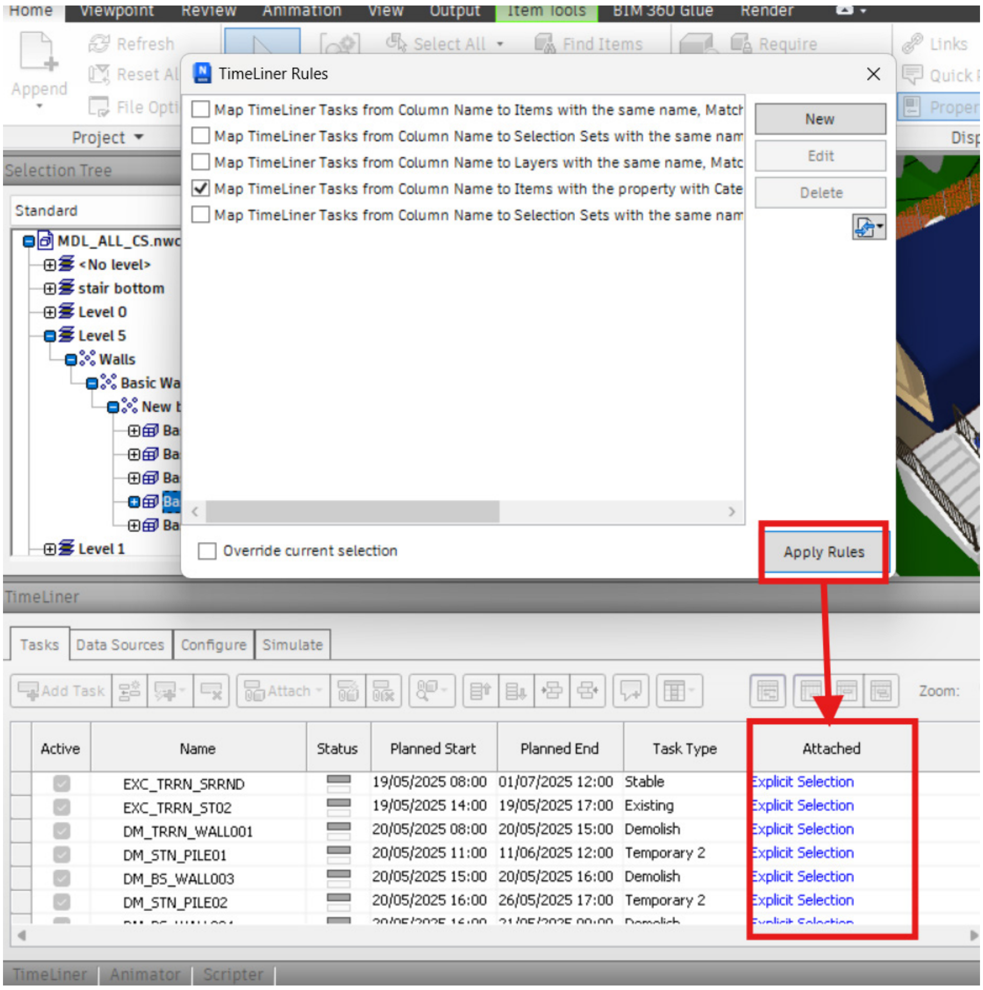


***Figure* 50.** *Applying Rules.*

Once the attachment was complete, the next step in the process was to modify the appearance of the items in the simulation. In order to create Appearances that were appropriate for the task at hand, the tool that was utilized was the *Configure* of the TimeLiner. The only thing that was required was to figure out how the item was supposed to be witnessed in accordance with the modification or creation of the item (see Figure 51).

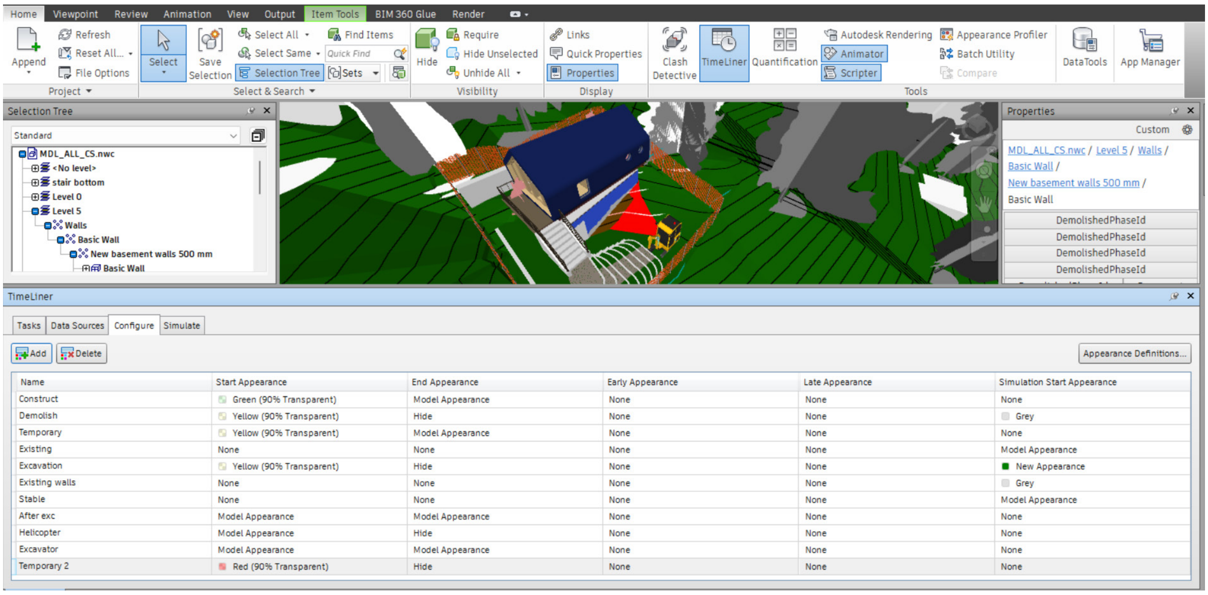


Figure 51. *Appearance configuratioon.*

In order to complete the simulation, one of the final steps was to create animations, such as the movement of the excavator or the helicopter that was bringing the modules. Due to the fact that each movement had to be manually entered before moving on to the next, this procedure took the most amount of time. The movement of the item is observed while switching from one diamond to another, as shown in Figure 52. Black diamonds are the snapped coordinates of every movement, and they are used to represent the movement of the item. *Animator* was the tool that was utilized to accomplish this. As can be seen in Figure 53, *Scenes* were created in the animator by selecting the elements that needed to be animated and then attaching them to the scene.

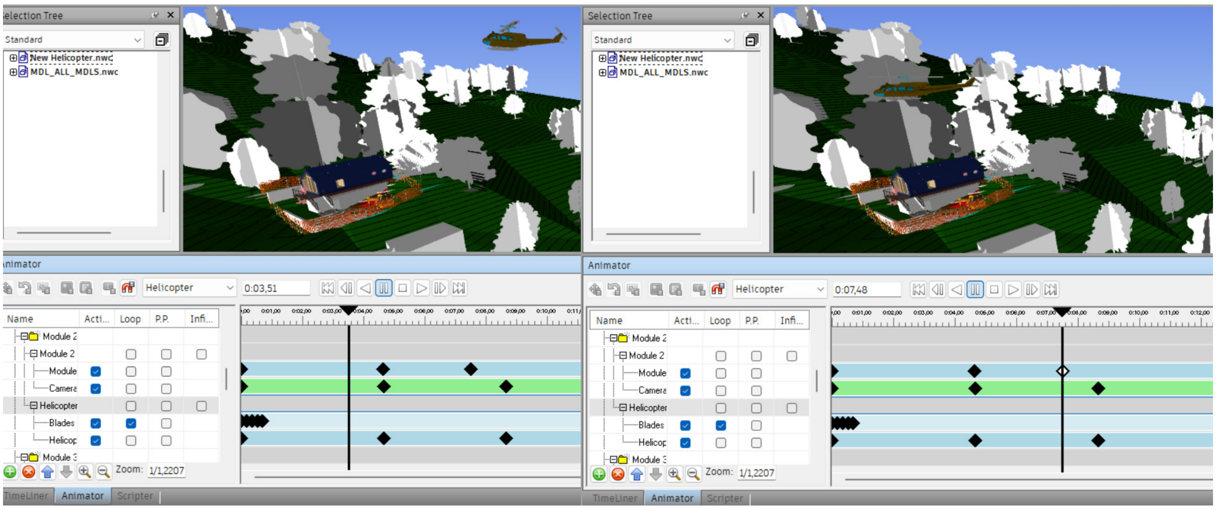


Figure 52. *Movement snapping.*

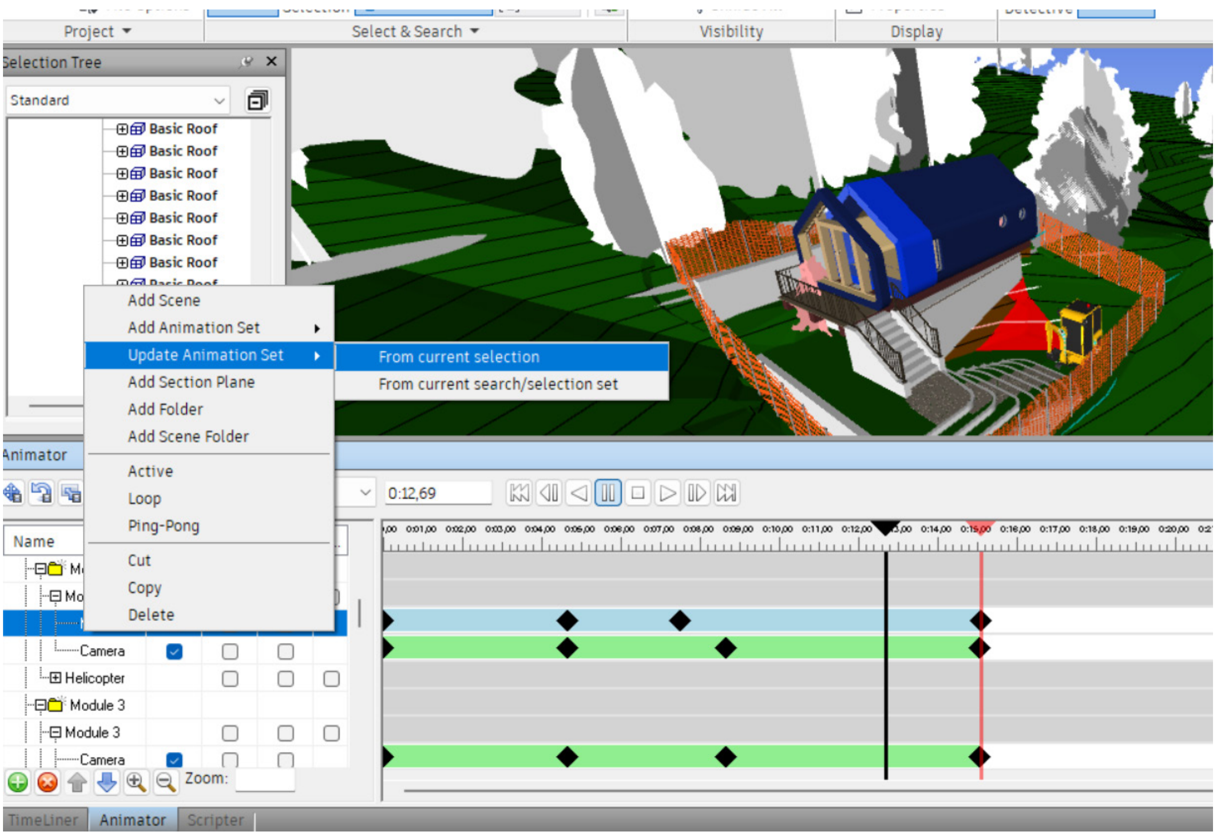


Figure 53. *Animation settings.*

In the end, *Scripter* was used to "direct" the animations, some of which included the rotating blades when the helicopter was in flight. In order to accomplish this, it was sufficient to create a new script, after which the main animation and its trigger were added to the properties of the *On Condition* in the *Events* (see Figure 54), and finally, the Actions were modified by adding the *Play Animation* and in its properties the animation of the blades was added to be played together with the helicopter animation, as shown in Figure 55 to complete the process.

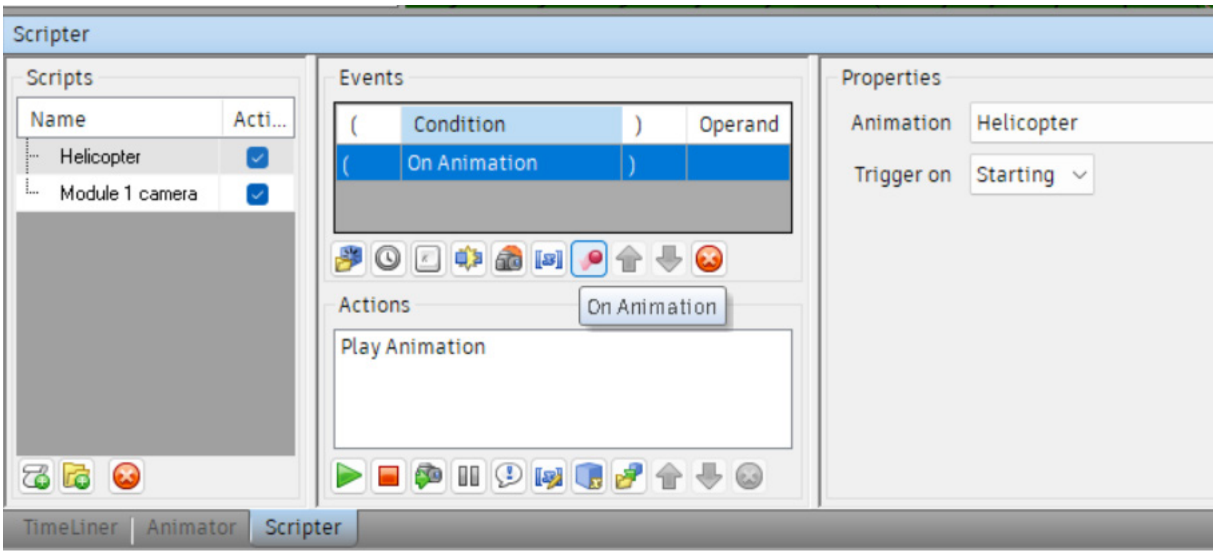


Figure 54. *Creating an event in Scripter.*

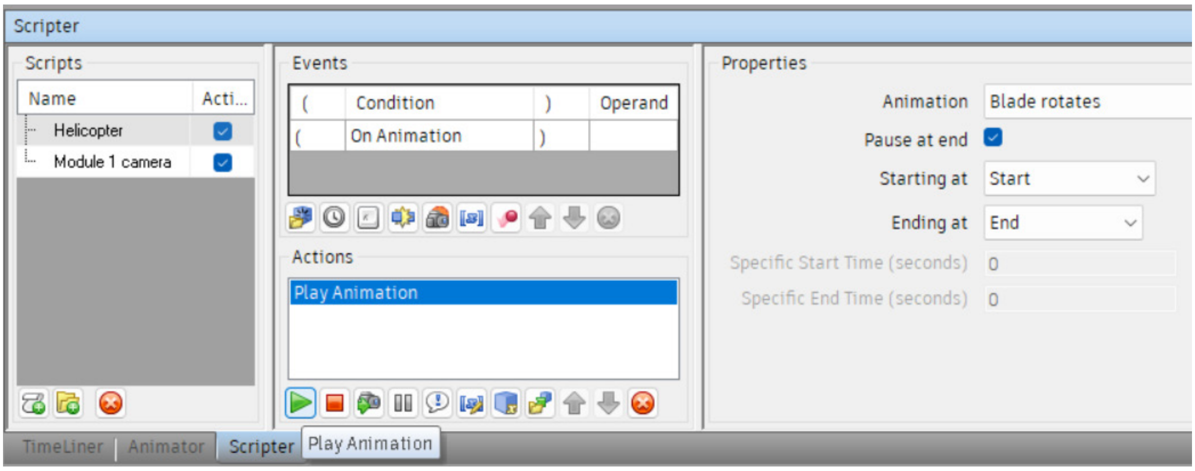


Figure 55. *Creating an action in Scripter.*

A simulation of the Construction Management could not be made until all of those steps had been completed (see Figure 56 & 57).

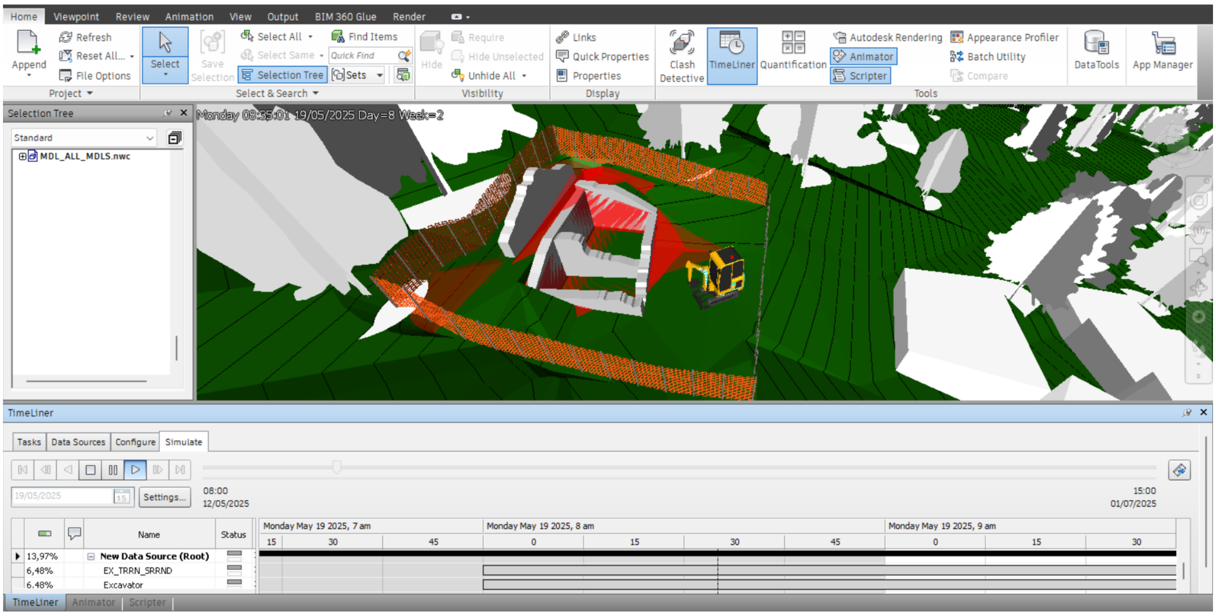


Figure 56. The *simulation of the excavation.*

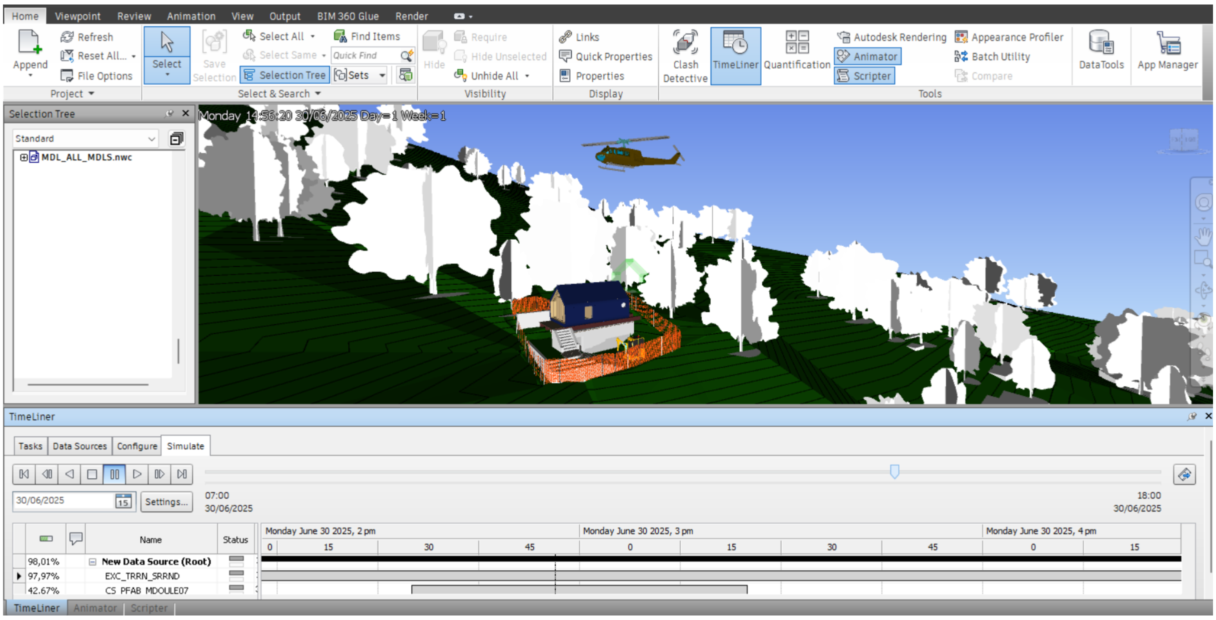


Figure 57. *The simulation of the helicopter transporting a module.*

4.4 XR development

The final step, which was also the most important part of the thesis in terms of the results, was the development of the extended reality. The lack of prior experience in programming and the software platforms used throughout the process made the task particularly challenging, as a solid technical expertise is required to handle it effectively.

For each and every reality, there were three applications that were developed. The first one was a virtual reality application that enabled users to visualize the design of the project before it was built and to make changes to it virtually. After some time had passed, an augmented reality application received permission to view the simulation integrated in the real world surrounding it and tracked on a particular image target. The final one was a magnetic resonance (MR) application that, despite the fact that it was unable to obtain concrete results to demonstrate, provided a solid idea for the future directions of research.

4.1.1 Virtual Reality Application

The development of virtual reality applications was a relatively quick process because there were already built-in programs available. The integration in Revit made it very simple to import the model into **Twinmotion 2024.1.2.** which made it possible to develop a virtual reality application. The rendering of the model was simple, and the editing of phase scenes and the saving of sets were both simple and straightforward (see Figure 58 & 59).

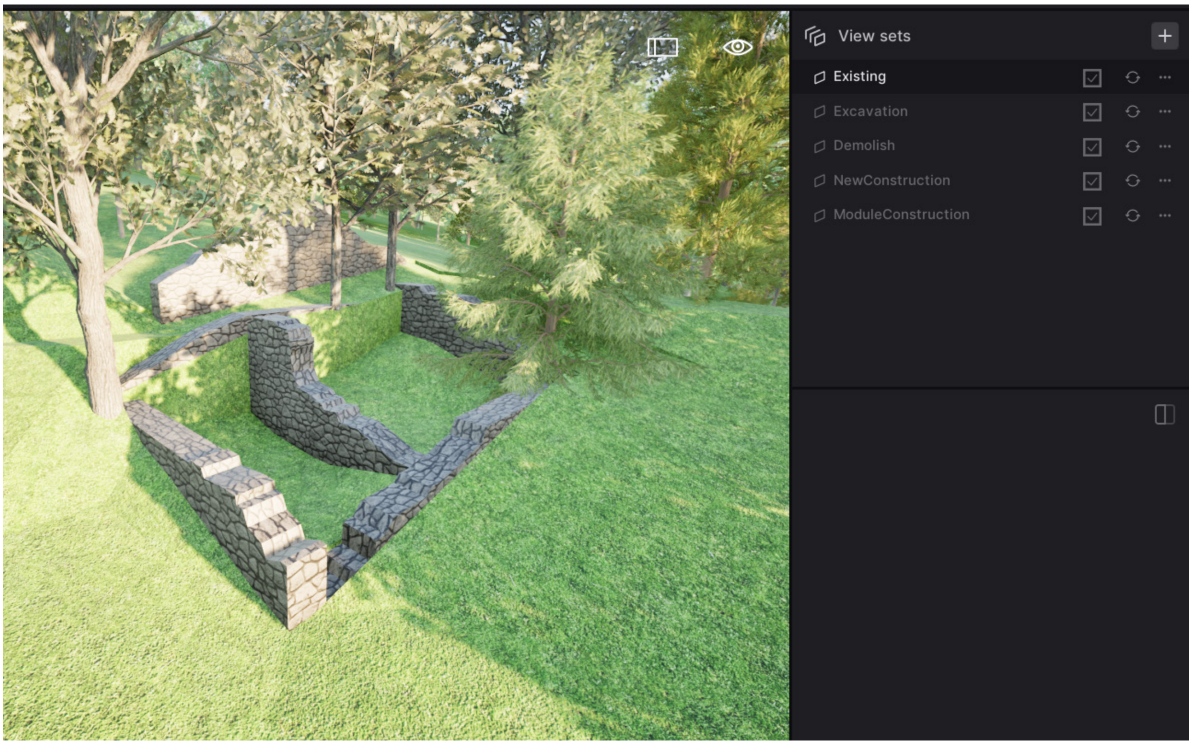


Figure 58. *Existing phase view set in Twinmotion.*

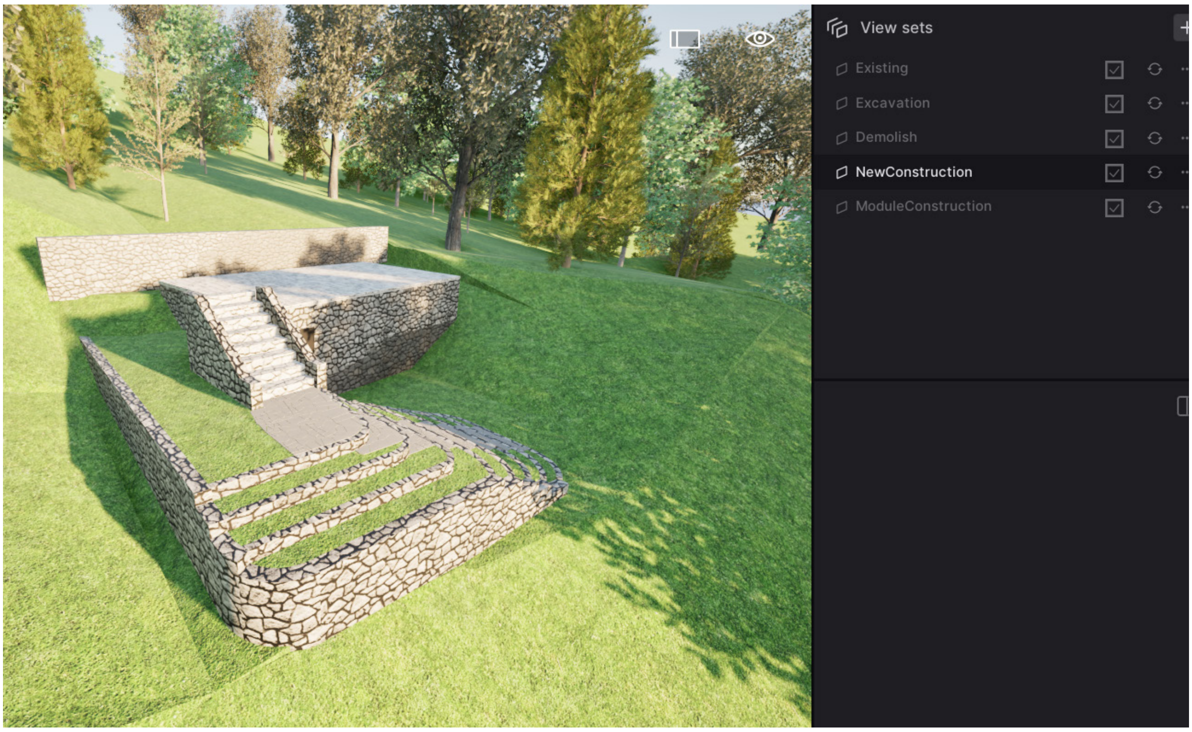


Figure 59. *Construction phase view set in Twinmotion.*

Following the addition of the materials and vegetation, as well as the creation of view sets, tests were carried out with the help of the **HTC Vive Pro2** virtual reality glasses. In addition to being able to move around inside the model and change the weather, it was also possible to add materials to the objects (see Figure 60 & 61).

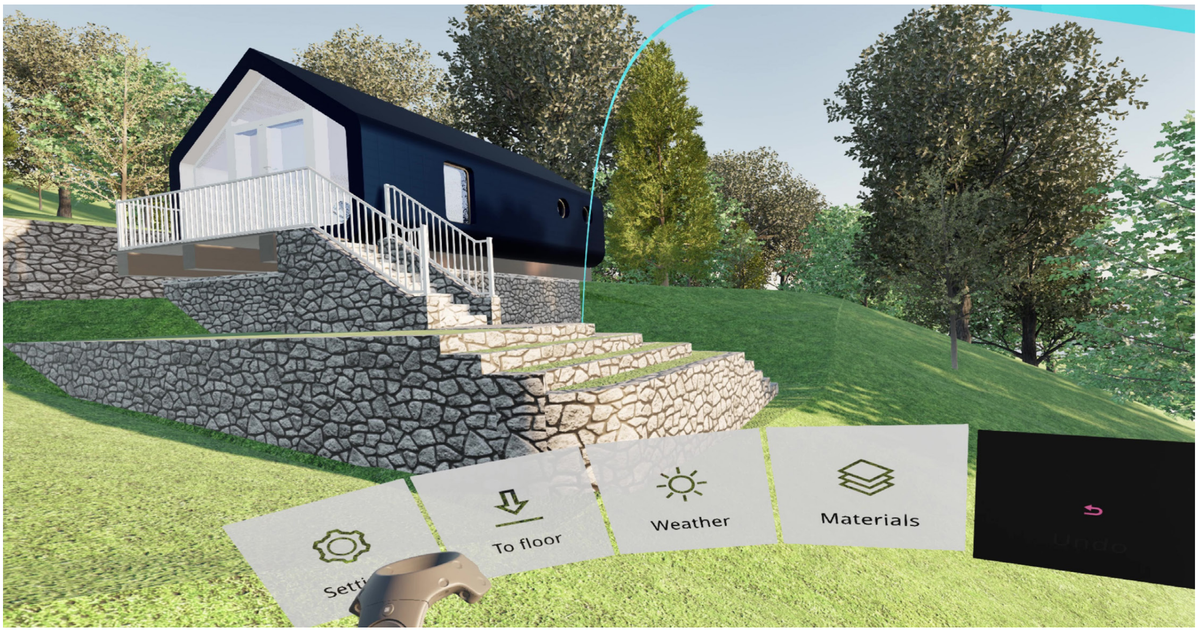


Figure 60. *Testing movements in VR application.*

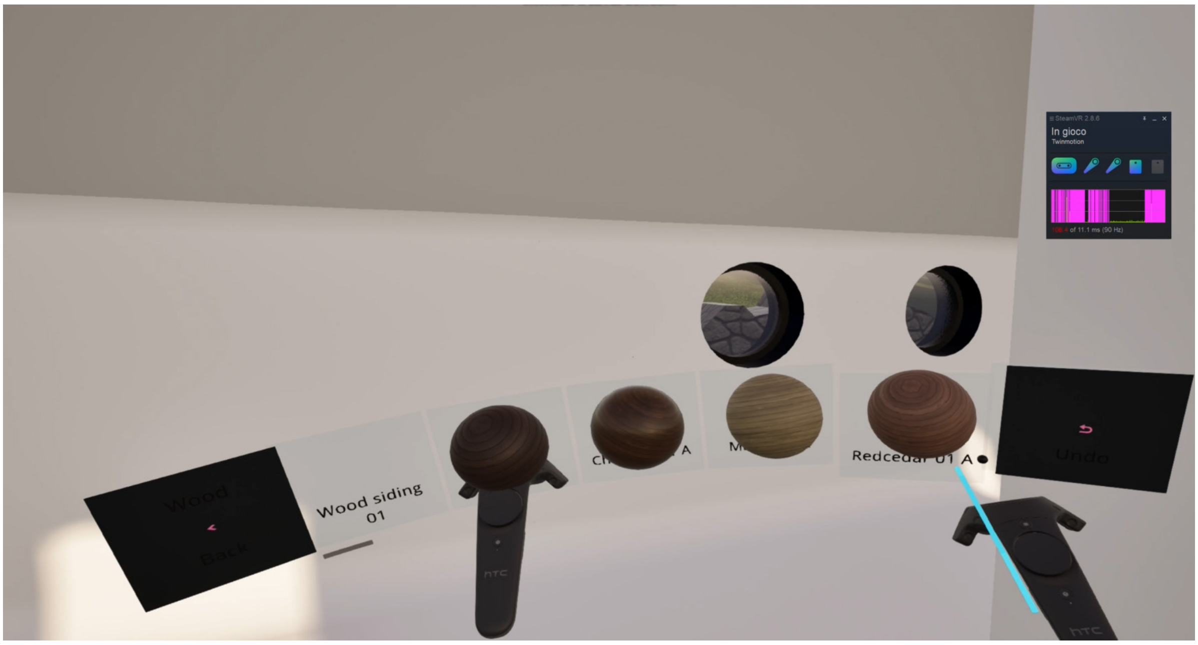


Figure 61 *Testing materials insde VR application.*

4.4.2 Augmented Reality Application

Although the development of the AR application was simplified in terms of the application's ability to run thanks to the utilization of the **Vuforia SDK**, the process was time-consuming overall due to the built of the scene and the animation creation.

At this point in the methodology, it was discovered that there was a problem with interoperability between the programs. The process of importing the model into **Unity 2022.3.41f1** was a difficult one from the perspective of receiving the model with its materials and entities being independent of one another. By exporting the model as FBX from Revit and then importing it to **Blender 4.2.2 LTS** to edit it before importing it into Unity, which is the method that is typically used, the model appeared to be completely gray (see Figure 62), and it was not possible to edit the materials separately of some entities.

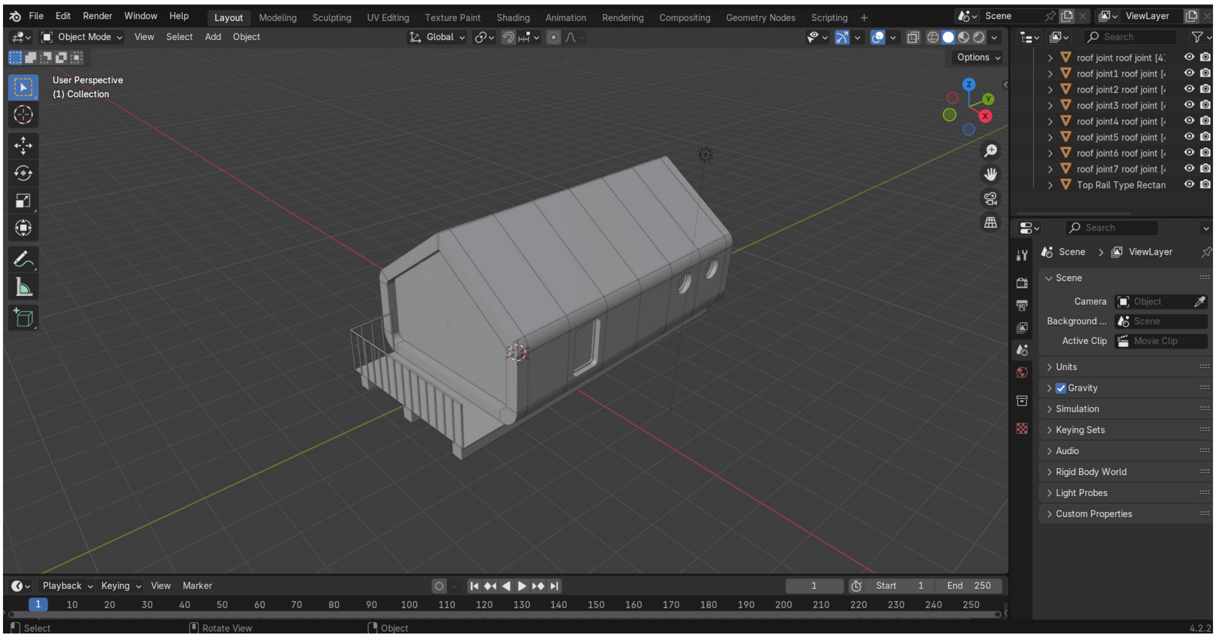


Figure 62. *Importing FBX in Blender trial.*

For the purpose of reducing the amount of time spent on the process and acquiring the exact same model across all platforms, a different approach was investigated, and the **Speckle** data hub (see Figure 63) was discovered. In addition to providing an immediate connection between the programs, this is an excellent tool that can be attached to the software platforms that were utilized during the process of developing the thesis. As a consequence of this, the model was transferred from Revit to Speckle, and then from Speckle it was “dragged” into Blender for pre-Unity editing. Furthermore, the blender file was finally able to be imported into the assets of the Unity project that was created.

Figure 63. *3D model in Speckle.*

Following the loading of the model, it was time to configure the scene for the AR application. In order to accomplish this, it was necessary to set up the camera that the application will use to function. The hierarchy had been updated to include Form Vuforia’s

Prefabs AR Camera, which is responsible for operating the camera that is connected to a computer (see Figure 64).

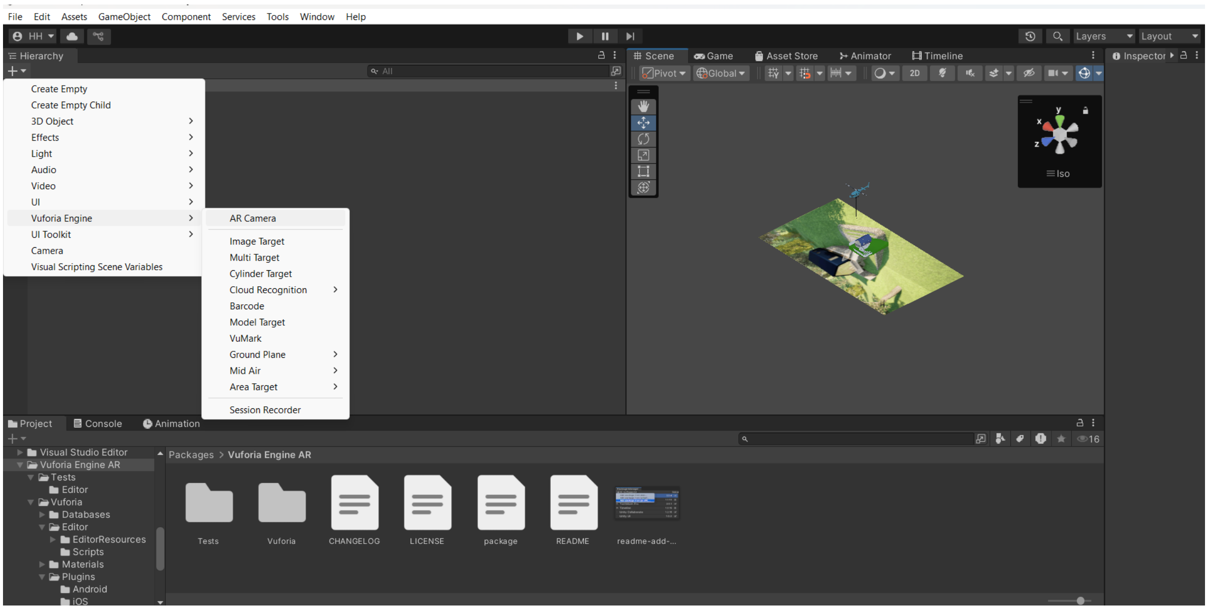


Figure 64. Adding AR Camera.

Image Target was added to the hierarchy in accordance with the sequence that is depicted in Figure 65. Whenever the Image Target game object is selected in the Inspector window, there is already an *Image Target Behaviour* script that is attached to it. This script allows the user to add the image (see Figure 65). The picture was inspected using the *Database* type in order to determine whether or not the image that was uploaded was appropriate for tracking with Vuforia's online Target Manager database (see Figure 66). It was essential that the image be in the RGB color format.

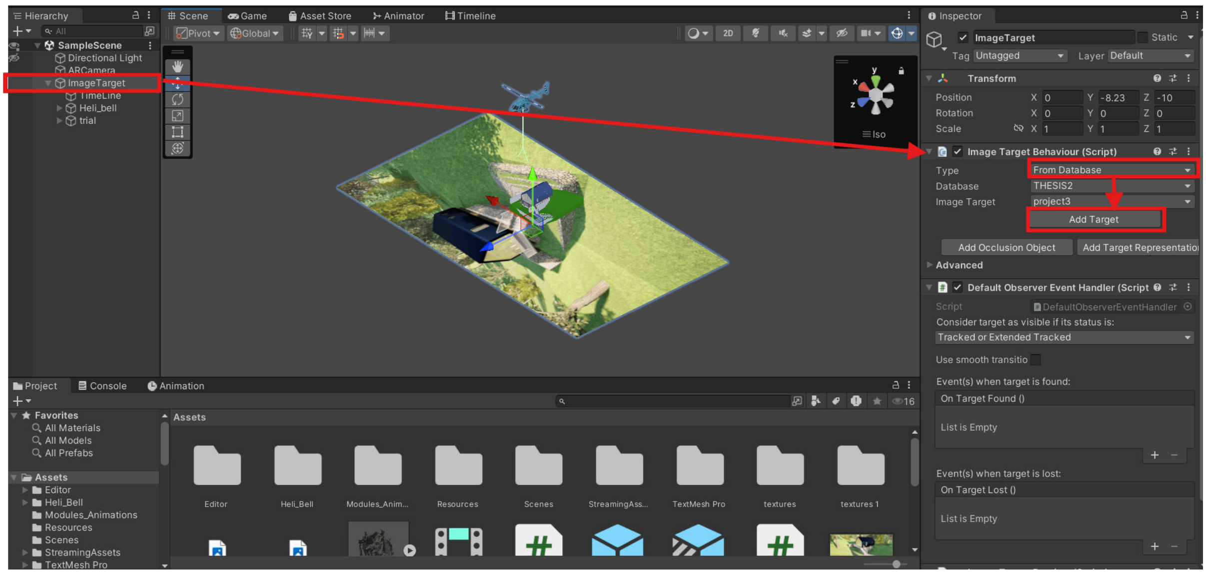


Figure 65. *Adding Image Target.*

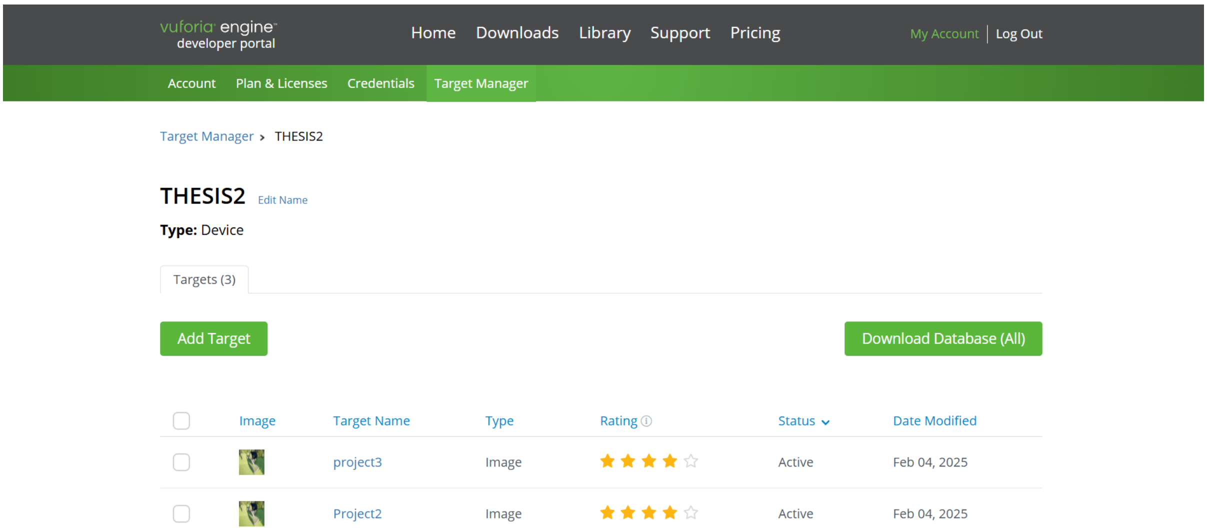


Figure 66. *Vuforia's online Target Manager Database.*

Following that, the next step, which was also the final step before testing, was to create the animations and then make them play according to a specific sequence. From a logical standpoint, it was very similar to the animation creation process in Navisworks. In order to accomplish this task, all that was required was to click on *Animation* in the Window menu in order to activate the animation window. Following that, the objects that required animation were chosen, and animation assets were added by clicking on the *Create* button in animation window. As in Navisworks, animations were created simply by snapping the movements when they were needed (see Figure 67).

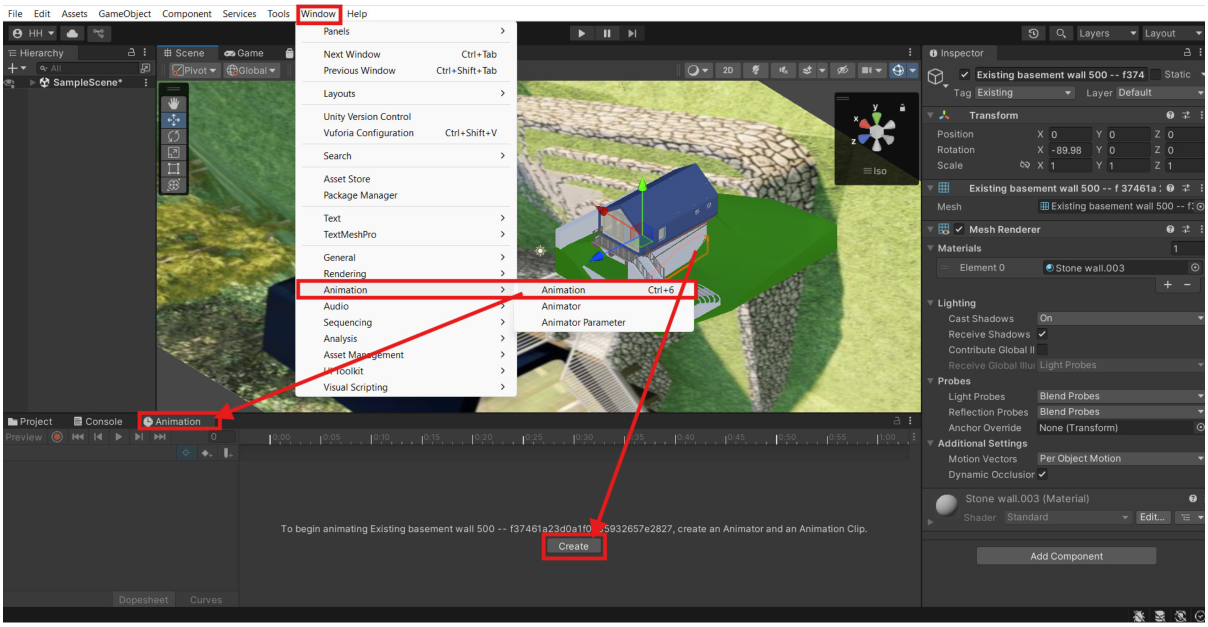


Figure 67. *Creating animation assets.*

A game object was set up in the Hierarchy so that it could be used for the sequence. Activating a window was accomplished in the same manner as before by visiting the Window menu and selecting *Sequencing*, followed by *Timeline*. Then, in the Inspector window of the Timeline game object, it was necessary to add the *Playable Director* component and add the *Timeline Asset* that had been created. Ultimately, the timeline was modified by including *Animation Tracks* and throughout the process (see Figure 68)

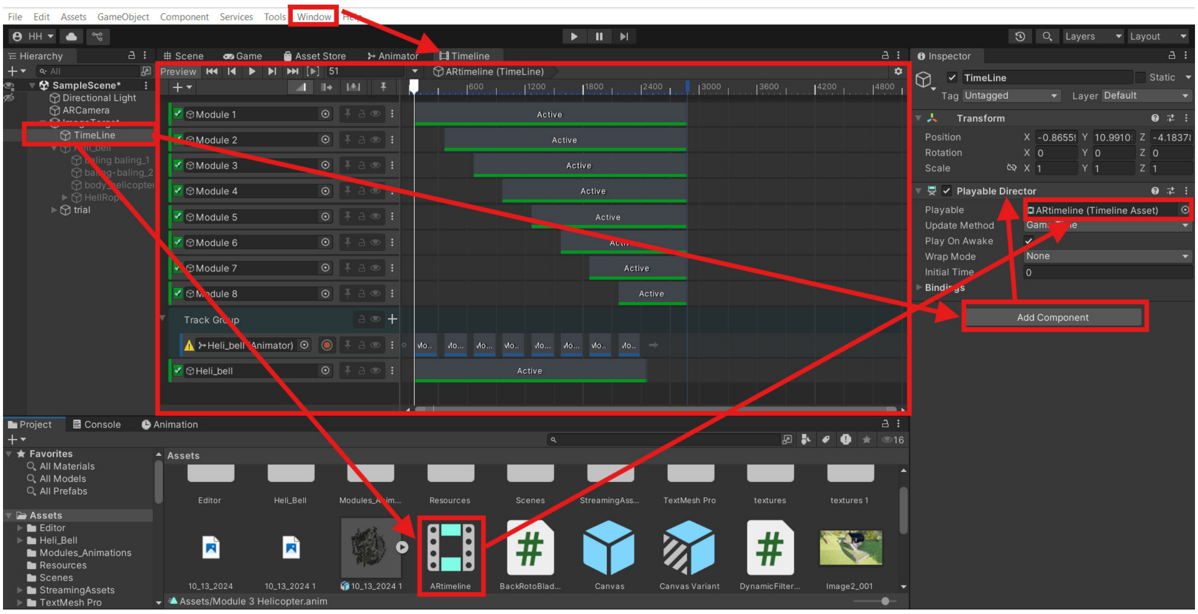


Figure 68. *Creating Timeline Asset for sequencing.*

Play was finally used to put the application through its paces for testing. Excellent results were achieved by using a webcam in conjunction with the target image displayed on a monitor (See Figure 69 & 70).

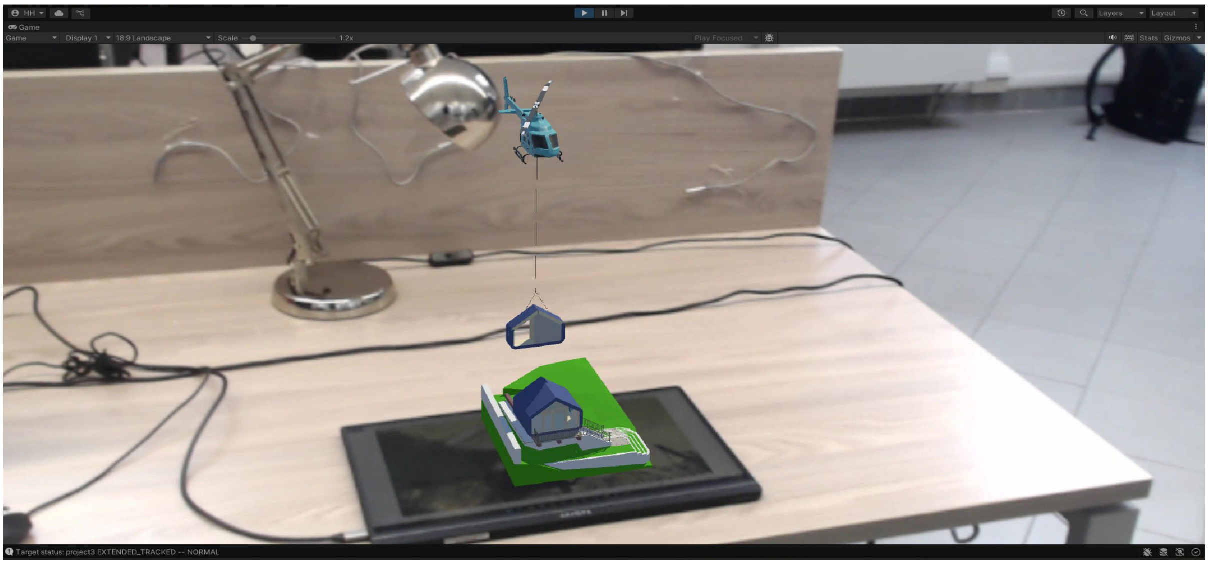


Figure 69. *Testing the AR application in lab 1.*

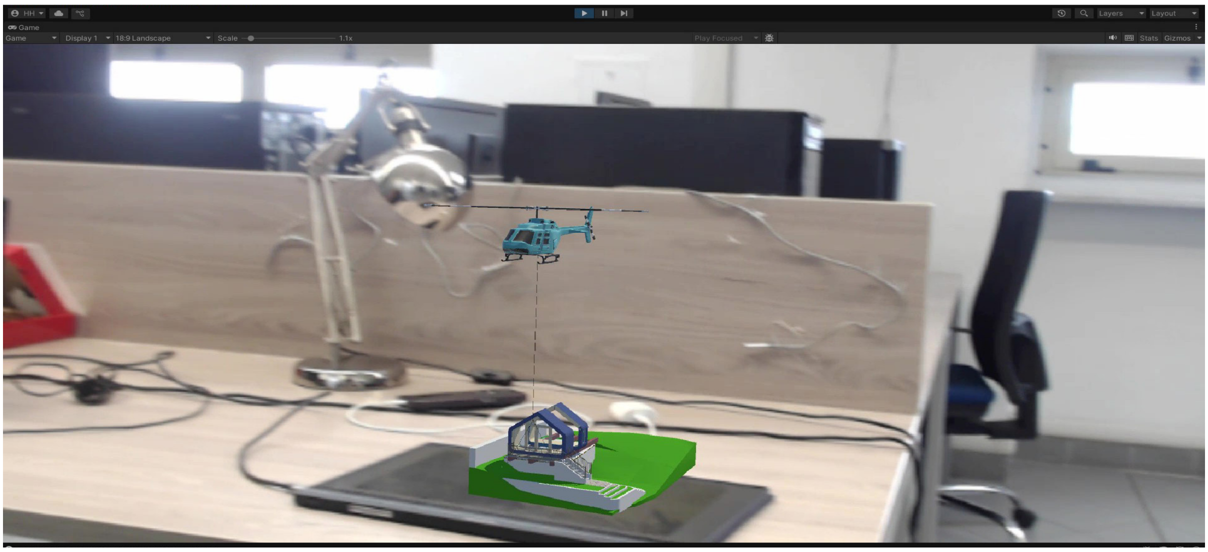


Figure 70. *Testing the AR application in lab 2.*

4.4.3 Mixed Reality Application

At that point, the thesis was unable to produce any noteworthy outcomes. The rationale was that this type of development is at an advanced stage and requires a great deal of expertise and understanding. Despite numerous attempts, no clear-cut application was able to be implemented. However, the development itself is a suggestion for future paths.

Another project was produced using Unity. The idea was to create a menu application that was easy to use in Mixed Reality. Modern artificial intelligence development was essential at that point, helping to guide the process and generate the scripts needed for the application. For instance, following menu Ui and button configuration. The ability to filter items and construction stages was the goal (see Figure 71). A dynamic menu with buttons that change color when turned on and off, as well as a connection between layer filtering and tag filtering buttons, were requested from **ChatGPT 4o mini** (see Figure 72).

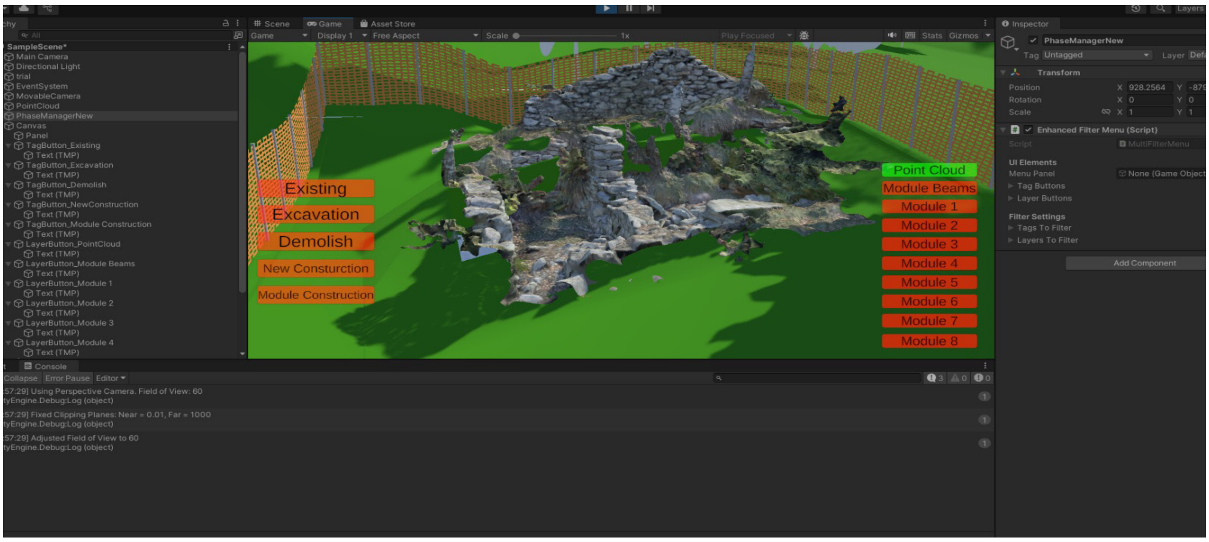


Figure 71. *Turning only the Point Cloud on for testing.*

Here's the complete updated **ToggleTagFilter** and **ResetLayersForTag** methods for reference:

csharp   Copy   Edit

```csharp
// Toggles a tag filter and resets associated layers
void ToggleTagFilter(string tag, Button button)
{
    bool isActive = activeTagFilters.Contains(tag);

    if (isActive)
    {
        activeTagFilters.Remove(tag); // Disable the tag
    }
    else
    {
        activeTagFilters.Add(tag); // Enable the tag
        ResetLayersForTag(tag); // Reset layers for this tag
    }

    ApplyFilters();
    UpdateButtonVisual(button, !isActive);
}

// Resets all layers related to a tag to their initial state
void ResetLayersForTag(string tag)
{
    if (!taggedObjects.ContainsKey(tag)) return;

    foreach (var obj in taggedObjects[tag])
    {
        int layer = obj.layer;

        // Ensure the layer exists in the layersToFilter list
        int layerIndex = layersToFilter.IndexOf(layer);
        if (layerIndex >= 0)
        {
            // Reset the layer state (off/red by default)
            activeLayerFilters.Remove(layer);

            // Update the corresponding layer button
            Button layerButton = layerButtons[layerIndex];
            UpdateButtonVisual(layerButton, false); // Red (off)
        }
    }
}
```

Figure 72. *ChatGPT scripting.*

Immediately following this, the examinations began to take place. By utilizing the **Magic Leap SDK**, an application was developed and made to run on **Magic Leap 2** MR glasses. In order to get a better look at the menu, there was a view that could be navigated around (see Figure 73). It was not possible to interact with the menu or move around inside the model, which is a very unfortunate situation. One of the reasons the menu was removed from the scene was because it was presumed that the problem was caused by the canvas settings. This time, it was possible to move around inside the model itself within the dimensions that correspond to the real world (see Figure 74). From the user's perspective, however, this application did not provide any control over anything.

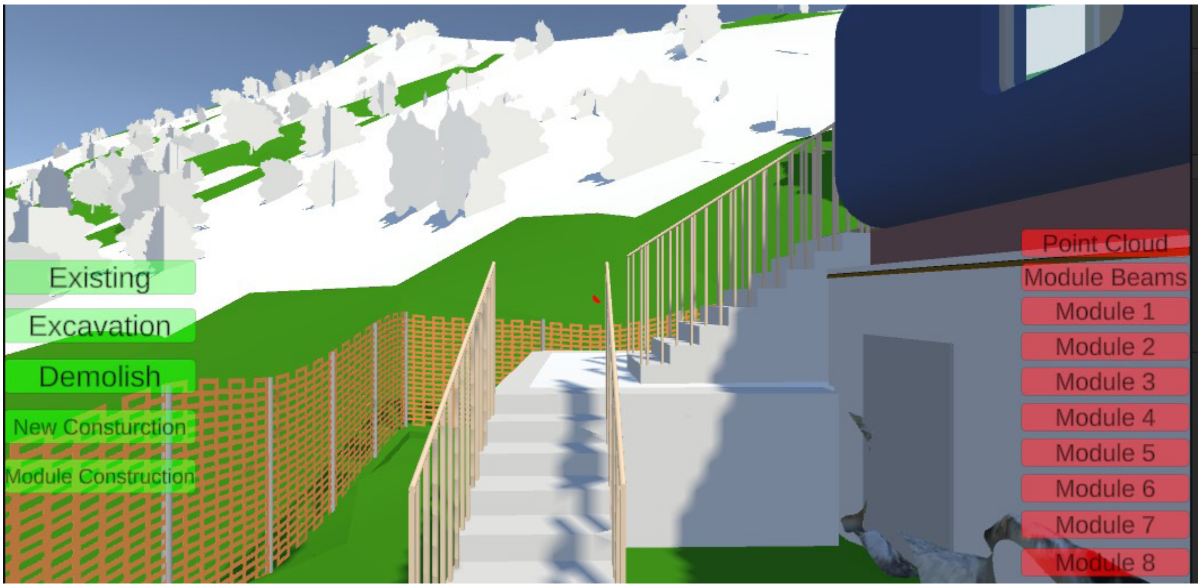


Figure 73. *Testing the application with Menu.*

Figure 74. *Testing without menu.*

It was not possible to recover the file after it had been corrupted as a result of additional editing and script additions. Since this was the case, a different project was developed. Simply gaining an understanding of the model in relation to the real world that surrounded it was a straightforward and uncomplicated process (see Figure 75 & 76).

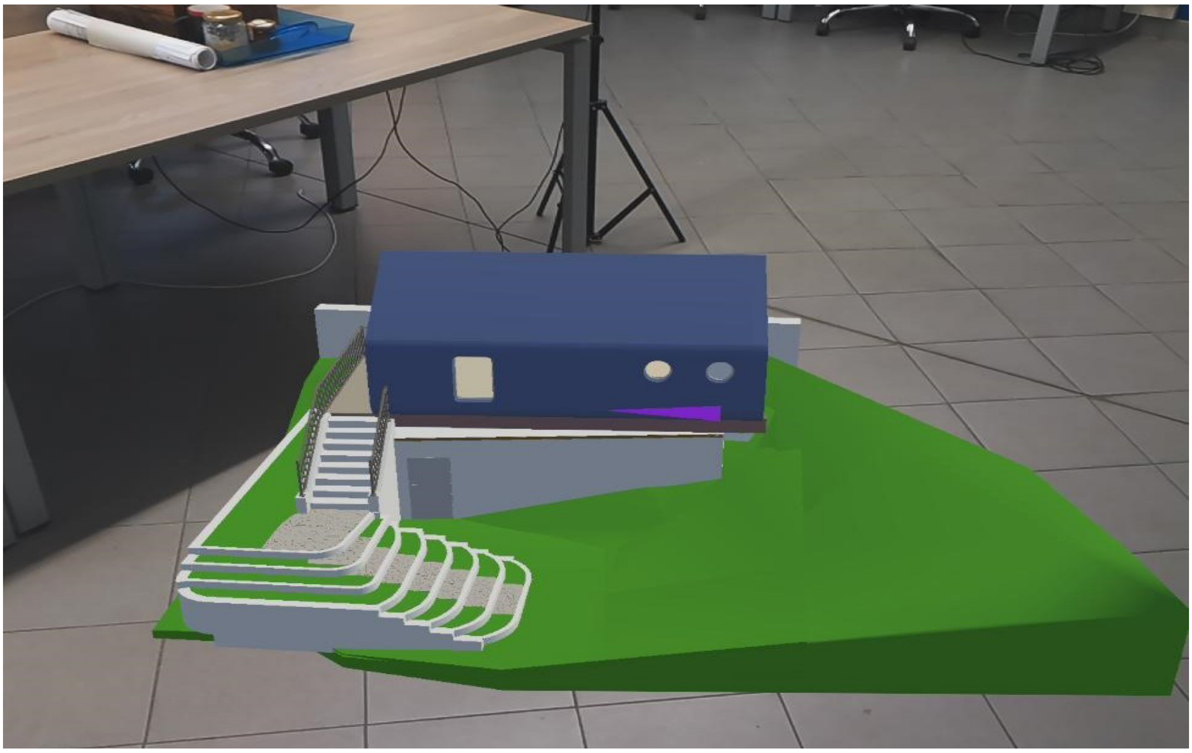


Figure 75. *Testing the application in the Lab 1.*

Figure 76. *Testing the application in the Lab 2.*

5. Results

The results of this study show that building information modeling (BIM 4D) and Extended Reality (XR) taken together have great potential to revolutionize construction management. This is especially true in challenging surroundings, such Piedicavallo's mountainous topography. The approach applied made it possible to create several digital tools, which were subsequently assessed in respect to their importance in the building process. The frequency with which these instruments are used, the expected use by different stakeholders, and the possible contribution they could make to the planning, implementation, and monitoring of building projects define their relative importance either primary or secondary.

The **Phased Revit Site Model** has great potential to be the main document since it is so central in organizing design, scheduling, and structural accuracy. Apart from providing the framework for all later simulations and XR projects, it arranges the project into precisely defined building phases and integrates the Work Breakdown Structure (WBS) to enable effective task management and sequencing. Because it provides a complete framework for all those engaged, it affects not only architects and designers but also construction managers and project planners. Furthermore, the model can be the main data source for export into Navisworks for the aim of scheduling simulations and XR platforms for immersive visualization, so supporting its central pillar status in the digital workflow.

The Navisworks Simulation Package is thus one of the most important components of this research since it is among the most important instruments in building management coordination. It can help construction managers and project planners to maximize scheduling, identify task dependencies, and spot potential conflicts before construction starts. Incorporating the **Gantt chart** schedule exported from Microsoft Project helps one dynamically link the sequencing of building projects to a visual simulation, so enhancing the decision-making process. Navisworks can also be quite important in risk reduction for the aim of spotting spatial conflicts between mechanical and structural elements. This could help to lower the occurrence of mistakes and stop expensive work. As such, the simulation model might prove to be absolutely essential in terms of guaranteeing the viability of the project and the efficiency of the workflow.

Extended reality tools help to further increase the benefits of digital construction management. **The Virtual Reality (VR) Application** developed in Twinmotion has great potential to be the main tool since it could influence pre-construction validation and stakeholder involvement. Project owners, investors, and designers can be able to completely submerge themselves in a full-scale digital replica of the project, enabling more open communication and expeditious decision-making process speed. Virtual reality (VR) can help to enable a dynamic review of building phases unlike conventional two-dimensional drawings or fixed three-dimensional models. This lets interested parties investigate spatial layouts and material uses interactively. When tested in real-world building contexts, it could help to improve project understanding and spatial awareness.

Apart from pre-construction visualization, **the Augmented Reality (AR) Application** could become a required tool for real-time on-site verification. Developed with Unity and the Vuforia Software Development Kit (SDK), it could let building managers and contractors overlay digital models onto the real world, allowing precise structural component alignment. Regarding quality control, the augmented reality tool could be quite helpful since it allows the instantaneous recognition of any deviations between the intended and actual development of building. AR could enable the synchronization of digital and physical site conditions, so helping to lower building mistakes. Combining real-time tracking with Speckle will help to achieve this. Its ability to streamline verification and enhance workflow coordination could help it to be positioned as a necessary element of the running of building projects.

Assuming it to be completely functional, **the Mixed Reality (MR) Application** is the most innovative technological tool available in the field of construction management. Mixed reality (MR) gives users an interactive space where they might control digital models inside the framework of a real-world building site. This goes against augmented reality (AR), which mostly consists of overlays, and virtual reality (VR), limited to pre-construction visualizing. By allowing construction managers to dynamically control and change structural elements in real time, this tool could help the virtual and physical worlds to be seamlessly merged. By interacting with the model using MR devices, such Magic Leap 2, one can provide hands-free navigation together with a simple interface for project monitoring and change. MR can provide an unparalleled degree of precision and flexibility by means of the integration of spatial visualization and interactive control, so defining itself as a required instrument for the future evolution of digital construction management.

5.1 Evaluation

The following table shows the relevance of every final document depending on the possible contribution it could make to building management. Documents classified as **Primary** receive *(1)* point, documents classified as **Secondary** receive *(½)* point, and documents judged insignificant for some stakeholders receive no points for the scoring system's purposes. The grand total score reflects the general relevance of every document among the several roles engaged in the building process.

Table3. Document Relevance evaluation:

Actor/ Stakeholder	Revit Model	Navisworks Simulation	VR Application	AR Application	MR Application	
Client / Project Owner	High-Level Design (1)	Overall Construction Flow (1)	Immersive Project Walkthrough (1)	On-Site Progress Demo (1/2)	Interactive Project Preview (1)	
Investors / Stakeholders	Project Blueprint (1)	Dynamic Process Simulation (1)	Realistic Visualization (1)	–	Future-Ready Innovation (1)	
Architects / Designers	Core Design Model (1)	Coordination Tool (1/2)	Design Walkthrough (1)	Design Verification (1/2)	Interactive Spatial Design (1)	
Construction Managers / PMs	Planning Baseline (1)	Scheduling & Clash Detection (1)	Pre-Construction Review (1/2)	Real-Time On-Site Guidance (1)	Fully Integrated Workflow (1)	
Field Contractors / Supervisors	Supporting Details (1/2)	Task Coordination Overview (1/2)	–	Quality & Safety Checks (1)	Interactive On-Site Control (1)	
BIM Specialists / Modeling Experts	Central BIM Model (1)	Model Integration (1/2)	–	–	Advanced Model Interaction (1)	
	5.5	4.5	3.5	3	6	Total score

Based on the assessment of the relevance of the document depending on its expected impact across all stakeholders, the **MR Application** has the potential to be the most transforming tool since it incorporates real-time interaction with digital construction models. MR could significantly raise the efficiency of decision-making in complex building environments by means of its potential for real-time changes and perfect workflow integration.

Not far behind is the **Phased Revit Model**, which provides the basis on which the whole digital workflow is erected. It is in charge of planning the phases of the project and enabling flawless integration of several instruments. Over the whole project life, it can be regarded as indispensable since it is in charge of scheduling, phase organization, and coordination of structure data.

Furthermore, indispensable is the Navisworks Simulation Package, especially with relation to project scheduling and execution respectively. By means of the integration of digital simulations with building sequences, it is feasible to improve scheduling efficiency and reduce associated assignment dependent errors. Conversely, the fact that it scored somewhat lower than the Revit Model and the MR Application suggests that, even if it is absolutely essential for project coordination, it remains a tool for planning and analysis instead of an interactive decision-making interface.

Two areas where the **Augmented Reality (AR)** Application is rather important are on-site validation and construction tracking. Real-time project evaluation especially benefits from this tool. Augmented reality makes it possible for engineers and site supervisors to directly overlay BIM data onto physical constructions, so allowing them to check construction alignment with project models, compare planned designs with actual progress, and find variations during the building process. Although augmented reality lacks the complete range of interactive features that virtual reality offers, its ability to close the distance between digital and physical building components in real time makes it a quite valuable tool for site management and quality assurance.

The **Virtual Reality (VR**) Application receives a lower score, thus even if it has the potential to be a helpful tool for stakeholder involvement and project validation, its use in the execution of real-time building projects is limited. It improves pre-construction knowledge, but it does not directly help with decision-making during active building projects.

The results suggest that in order to provide more solid and real-time building management, the enhancement of MR capabilities should take more relevance in next studies. Moreover, important is ensuring that BIM-based tools—such as Navisworks Simulation and the Revit Model—keep close relationship with these particular technologies. Given the lower score for virtual reality (VR), investments in the development of augmented and virtual reality (AR and MR) should also be directed more toward real-time, site-based applications rather than only pre-construction visualization.

6. Conclusion

This thesis explored the integration of Extended Reality (XR) technologies and Building Information Modeling (BIM 4D) to improve visualization, logistics, and workflow efficiency in a mountainous construction environment. Using Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), the research looked at how digital modeling and scheduling tools might enhance construction planning, coordination, and execution. The study was set up under a comprehensive approach including site surveys, phased BIM modeling development, Navisworks' construction sequence simulation, and XR applications for immersive and real-time interaction with the project.

The Mixed Reality (MR) application provides dynamic changes and real-time workflow integration—real-world interaction mixed with digital construction models—which results show can offer the most significant advantages in building management. Foundational to the whole digital workflow, the Phased Revit Model guarantees coordinated project planning and execution. Emerging as a key tool for construction sequencing and scheduling optimization allowing for improved decision-making and risk reduction is the Navisworks Simulation Package. Strong on-site verification capability of augmented reality (AR) allowed real-time comparisons between intended and actual building development. Virtual reality (VR) proved less important for real-time decision-making but mostly helpful in the pre-construction stage, helping stakeholder involvement and design validation.

While BIM-based planning tools remain vital for project coordination, the evaluation of the final documents emphasizes that interactive and real-time tools have the greatest potential for direct application in building sites. Especially in complicated and far-off building environments, the results imply that combining BIM 4D with XR technologies can maximize logistics, reduce errors, and improve efficiency.

Although the study provides a decent framework for technology-driven building management, it is crucial to acknowledge some limitations affecting the research conclusions. Furthermore, emphasized by the results are several future directions that might improve the integration of XR and BIM in building management.

6.1 Limitations

Though the results were positive, the research suffered several constraints that affected the degree of the analysis as well as the practical relevance of the conclusions. One of the most important constraints of the developed tools was their lack of actual use or testing. The tools were not really used on a building site even though the technique was able to replicate building processes and interactions. This limits our capacity to evaluate the whole influence of these instruments in practical environments. This results in the conclusions being obtained using digital simulations and theoretical analysis instead of empirical data gathering from active building environments.

Another restriction that was experienced during the development of XR was related with the technological constraints and software interoperability problems encountered. The challenges faced by importing and exporting data between Revit, Blender, and Unity required the application of extra processes, including Speckle for data transfer, which added still another level of complexity to the development phase. Moreover, performance restrictions in augmented reality and mixed reality devices hampered the ability to create high-detail models in real-time, suggesting that hardware has to be advanced to support applications for large-scale building.

The learning curve related with XR development also presented difficulties since the research needed self-learning in programming, animation, and interface development. This limitation limited the ability to apply advanced MR features, such gesture-based interactions and real-time model changes, which might have enhanced the outcomes even more. Moreover, the evolution of MR was just seen in a controlled environment instead of being tested in the field. As a result, not all conceivable outside factors—including environmental restrictions, lighting conditions, and tracking accuracy—were investigated in great detail.

The presumptions about data scheduling constituted another main obstacle in the navigation works simulation and Gantt chart integration. The fact that the project was not executed in real time resulted in projected timelines instead of real-time construction schedules deciding the dimensions of the tasks and their dependencies. Therefore, even if the method provides a disciplined approach to the efficiency of workflow and logistics, its efficacy would need to be confirmed with data from real-world actual projects.

The last consideration is that the research mostly focused on a single case study conducted in a far-off mountain area. This suggests that the outcomes could not be exactly pertinent in every building context. Urban or large-scale industrial projects require further modifications to the approach since the type of projects, the surroundings, and the logistical challenges can affect the applicability of XR and BIM integration.

6.2 Future Directions

The results of this study indicate several fascinating future routes that might be followed to improve the integration of XR and BIM in building management. Real-world validation of augmented reality applications is one of the most important areas that presents development prospects. Future research should mostly focus on the use of augmented and virtual reality technologies on currently under construction buildings. This will help the empirical data on the usability, accuracy, and impact on workflow efficiency of the applications to be gathered. Pilot projects involving real building teams and project managers would help to highlight any further changes that might be needed for general industry adoption and provide interesting study of the efficacy of these instruments.

Furthermore, very important should be the creation of MR applications capable of allowing more interactive and real-time on-site modifications. Development of controllers based on gestures, voice commands, and gestures supported by artificial intelligence inside MR platforms could greatly help in decision-making during construction. Furthermore, the dependability of digital overlays in live building environments would be improved as well if the spatial tracking and alignment accuracy of MR models with real-world constructions were improved.

Moreover, underlined in the study is the need of better interoperability between BIM tools and XR development platforms. Developing more flawless integration processes between Revit, Navisworks, and Unity or Unreal Engine will help to simplify the application for XR process. For those in the building sector with little programming knowledge, this would simplify application. Moreover, research on cloud-based augmented reality solutions might let on-site workers and remote project managers collaborate in real time, so enhancing the project coordination.

To enable augmented reality and mixed reality devices in building environments to run better, more research on hardware developments is required. Many head-mounted displays (HMDs) nowadays suffer with their visibility in the outdoors, battery life, and processing capacity, all of which limit their capacity to be used on-site for extended lengths of time. Future studies should assess XR devices with more construction-specific strength and durability. These devices should be able to retain high-performance tracking and rendering features while yet resisting demanding environmental conditions.

Ultimately, the use of artificial intelligence to automate XR applications offers still another important future research prospect. Further optimizing workflow efficiency would be the inclusion of machine learning models inside MR applications for the goals of construction progress analysis, error prediction, and task automaton. XR together with artificial intelligence-based predictive analytics could improve overall project management strategies, help to find schedule risks, and offer advised alternative sequencing options.

Dealing with these future directions will enable XR and BIM 4D to grow into a more whole, real-time tool for building management. Even more, the developments in hardware, software, and artificial intelligence integration will increase the acceptance and practicality of these technologies; hence, they are a required part of modern, technologically driven building projects.

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