Universidade do Minho
Escola de Engenharia

Luis Felipe Moreira Salas

AR-enhanced collaborative environment for Facility Management supported by OpenBIM

BIM A+ — European Master in Building Information Modelling

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BIM A+
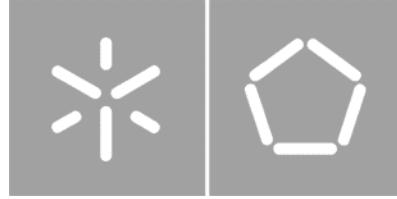
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environment for Facility Management
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BIM A+ European Master in
Building Information Modelling

Master Dissertation
European Master in Building Information Modelling

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Felipe M.

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Luis Felipe Moreira Salas

RESUMO

A transformação digital contínua na indústria da construção sublinha a importância da integração das tecnologias de Realidade Aumentada (AR) e Modelação da Informação da Construção (BIM). A AR desempenha um papel crucial na moldagem do futuro da tecnologia, e gigantes da tecnologia como o Google e a Apple estão a facilitar o desenvolvimento de experiências imersivas de AR no mundo real. Apesar da exploração teórica em estudos anteriores, ainda faltam ferramentas práticas e económicas que integrem de forma contínua os dados do BIM em ambientes de AR.

O objetivo principal desta pesquisa é criar uma Aplicação de AR baseada na Web de código aberto para a Gestão de Instalações de BIM (BIMFM), capacitando os utilizadores a aumentar a produtividade e reduzir erros durante as operações de gestão de instalações. Ao estabelecer um quadro independente, reduzindo a dependência de soluções de terceiros e promovendo a colaboração económica, tomada de decisões e melhoria da produtividade na indústria da construção, esta pesquisa aborda diretamente os desafios críticos da Gestão de Instalações (FM).

O estudo inclui uma demonstração de estudo de caso utilizando um Modelo BIM personalizado, com foco na testagem da compatibilidade com o ambiente de AR, garantindo o correto rastreamento de imagens, proporcionando uma experiência imersiva e permitindo o acesso em tempo real aos dados essenciais do BIM. Os resultados validam com sucesso as funcionalidades da aplicação. O trabalho futuro envolve a otimização da experiência do utilizador, a implementação de funcionalidades avançadas e a adaptação às tecnologias de AR em constante evolução. Esta pesquisa contribui significativamente para a evolução digital contínua na indústria da construção e promove uma abordagem capacitada e orientada para a comunidade na integração de tecnologia.

Palavras chave: Realidade Aumentada, Modelação de Informação na Construção, Gestão de Instalações, Industry Foundation Classes, WebXR.

ABSTRACT

The ongoing digital transformation in the construction industry underscores the importance of integrating Augmented Reality (AR) and Building Information Modelling (BIM) technologies. AR plays a crucial role in shaping the future of technology, and major tech giants like Google and Apple are facilitating the development of immersive real-world AR experiences. Despite theoretical exploration in prior studies, practical and cost-effective tools that seamlessly integrate BIM data into AR environments are still lacking.

The primary aim of this research is to create an open-source Web-based AR Application for BIMFM, empowering users to enhance productivity and reduce errors during facility management operations. By establishing an independent framework, reducing reliance on third-party solutions, and promoting cost-effective collaboration, decision-making, and productivity enhancement in the construction industry, this research addresses critical Facility Management (FM) challenges.

The study includes a case study demonstration using a custom BIM Model, with a focus on testing compatibility with the AR environment, ensuring correct image tracking, providing an immersive experience, and enabling real-time access to essential BIM data. The results successfully validate the application's functionalities. Future work involves optimizing the user experience, implementing advanced features, and adapting to evolving AR technologies. This research contributes to the ongoing digital evolution of the construction industry and fosters an empowered, community-driven approach to technology integration.

Keywords: Augmented Reality, Building Information Modelling, Facility Management, Industry Foundation Classes, WebXR.

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1. INTRODUCTION

The construction industry is currently undergoing a significant digital transformation, driven by the integration of AR (Augmented Reality) and BIM (Building Information Modelling) technologies (Chen et al., 2019; Ghobakhloo, 2020). Considering the convergence of smart mobile devices, AR holds immense importance in shaping the future of technology and human interaction with digital systems (Chen et al., 2019). Additionally, major tech giants like Google, with ARCore's Geospatial Creator, and Apple, with the unveiling of the Apple Vision Pro, are making AR accessible for developers to create immersive real-world experiences (Waisberg et al., 2023).

The combination of AR and BIM holds great potential to modernize construction practices, improve decision-making, enhance collaboration, and boost overall productivity. Numerous prior studies have explored the theoretical aspects of AR and BIM integration (Machado and Vilela, 2020; Nandavar et al., 2018; Sidani et al., 2022). However, user-friendly, cost-effective tools that seamlessly integrate BIM data into AR environments for practical construction applications remain in short supply (Hajji et al., 2022; Matoseiro Dinis et al., 2023; Schranz et al., 2021; Yigitbas et al., 2023). Multiple researches demonstrate progress in understanding the theoretical aspects of AR and BIM integration, but there is a need for more practical, real-world applications that can significantly impact the construction industry (Diao and Shih, 2019).

This thesis centers on the creation of an accessible AR-based tool that seamlessly integrates BIM information, leveraging the potential of WebXR rooted on IFC (Industry Foundation Classes), by establishing an independent framework. This process aims to reduce dependency on third-party solutions and proprietary alternatives, while empowering users with a versatile and cost-effective tool that enhances collaboration, decision-making, and productivity within the construction industry (Bao et al., 2022; Greenway et al., 2023; Sidani et al., 2022).

Capitalizing on open-source technology, such as WebXR, facilitates the establishment of an autonomous framework, obviating the necessity for third-party dependencies like Dalux, Unity3D, and Unreal Engine. This self-sufficiency fosters comprehensive research and interconnected studies, all shareable within the BIM community, thereby cultivating cultural independence and community-driven progression. Noteworthy among the advantages of employing WebXR based on IFC for AR is the ability to customize the AR environment according to specific needs and requirements. This, in turn, not only minimizes subscription and licensing costs but also empowers users to fine-tune their FM (Facility Management) tools without the obstacle of software expenses.

To create this practical Web-Based AR Application for BIMFM, a BIM Model was generated specifically for testing purposes. This model was created from a point cloud obtained through a laser scan of EQS Global's office, a Portuguese company specializing in Asset and Risk Management services. This tool holds potential to empower workers and technical teams with real-time access to critical BIM data, allowing them to visualize, manipulate, and explore BIM objects alongside their associated meta-data. Additionally, it is expected to enhanced collaboration, improve decision-making, and increase productivity in the construction industry.

The scope of the proposed AR-based tool is narrowed to the testing phase of the frontend, through a local server. All mentioned functionalities will be developed and tested, embracing web APIs, while adopting an open-format approach for improved data quality and interoperability between different types of devices. The application will be accessible through a web-based client, ensuring compatibility with various AR platforms, including: mobile phones, HMD (Head Mounted Display), smart-glasses, etc. The development and implementation of the application will prioritize a user-friendly interface and interaction methods optimized for mobile devices.

This research also focuses on fully utilizing the IFC file format. Many studies in the field employ game engine software such as Unity3D or Unreal Engine for virtual environments. However, these often require plugins to link with BIM software, which can hinder the utilization of the IFC file format and lead to data loss during conversions (Borrmann et al., 2018; Farghaly et al., 2018). In contrast, this framework, based on WebXR and IFC, ensures data integrity across different devices and operating systems.

The document is structured into five sections, with the initial section being the current introduction. The second section comprises a comprehensive literature review covering AR and BIM, including topics like FM empowerment via BIM, BIM interoperability, key cases of AR application in BIM-FM, and fundamental concepts of web application development. The third chapter outlines the web application development process, encompassing assumptions, principles, and user interface capabilities. The fourth chapter details a case study, specifying the Level of Information Need, BIM Model creation, and final outcomes derived from the AR application. Finally, the fifth chapter provides conclusions drawn from the study and suggests potential future developments for the application.

The source code can be accessed on GitHub: https://github.com/Felipemore96/BIM-A-Dissertation.

2. AUGMENTED REALITY AND BIM

2.1. AUGMENTED REALITY (AR)

2.1.1. General Overview

This research is rooted in the concepts of AR and XR (Extended Reality). AR refers to a technology that overlays digital information, such as images, videos, or 3D models, onto the real-world environment, typically viewed through devices like smartphones, tablets, or AR glasses. AR enhances the user's perception of reality by blending virtual elements with the physical surroundings, allowing users to interact with both real and digital elements in real-time (Vasarainen et al., 2021). XR is an umbrella term that encompasses all immersive technologies, including Virtual Reality (VR) and AR (Tremosa, 2023). XR is used to describe the spectrum of experiences that range from completely virtual environments to the integration of digital content into the physical world (AR) and scenarios that merge both virtual and real elements. This term highlights the continuum of experiences that technology can provide, enabling users to engage with digital content in various levels of immersion and interaction (Vasarainen et al., 2021).

The roots of AR can be traced back to the visionary ideas of Morton Heilig in the 1950s, who sought to create an immersive cinema experience engaging all senses, leading to the prototype Sensorama in 1962. Ivan Sutherland's invention of the head-mounted display in 1966 and his subsequent creation of the first AR system using optical see-through technology in 1968 marked significant advancements. In 1975, Myron Krueger's Videoplace allowed users to interact with virtual objects, pushing the boundaries of AR experimentation. In an industrial context, Tom Caudell and David Mizell introduced the term "Augmented Reality" while discussing its advantages over VR in aiding aircraft assembly. These historical milestones form the foundation of AR's evolution, shaping its development and diverse applications across various industries (Carmigniani and Furht, 2011).

AR is a state-of-the-art technology, as defined by Chen (et al., 2019), that merges virtual information with the real world. Employing a diverse range of technical means, including Multimedia, 3D-Modelling, Real-time Tracking and Registration, Intelligent Interaction, Sensing, and more, AR achieves its transformative capabilities. Its principle revolves around the strategic application of computer-generated virtual information, such as text, images, 3D models, music, video, etc., into the physical environment following a simulation process. By combining these two streams of information, AR fosters a harmonious and symbiotic relationship, culminating in an enhancement of the real world's perceptual and interactive dimensions. Another interesting take on the concept of AR is by Craig (2013), who did not see it as a technology, but as a technical medium that uses other technologies. For example, he stated that VR is a "special case" of AR or vice versa because VR is a fully synthetic environment.

AR stands at the forefront of the technological revolution that blurs the boundaries between physical and virtual worlds. It exists within the larger spectrum of immersive technologies called the Reality-Virtuality Continuum, which relates to the mixture of classes of objects presented in any particular situation, as illustrated in Figure 1(Milgram and Kishmio, 1994).
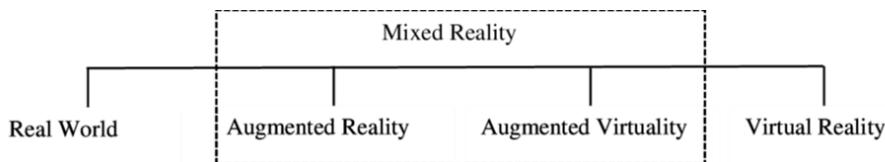
Figure 1 - Reality-Virtuality Continuum (Milgram and Kishmio, 1994)

Within the framework of the Reality-Virtuality Continuum, one end is occupied by "real environments," signifying settings comprised solely of tangible objects, while the opposite end is characterized by "virtual environments," representing the realm of VR. In this context, VR refers to an immersive environment where the participant observer becomes fully immersed and gains the ability to interact within an entirely computer-generated world. Additionally, the diagram introduces the concept of MR (Mixed Reality), encompassing environments that lie along the scale of transition between virtual and real domains (Milgram and Kishmio, 1994).

The RV Continuum was simplified by Tremosa (2023) into a spectrum of immersion, where one end is low immersion and the other end is high immersion. Based on this simplification, MR is defined as a technology that allows not only the superposition of digital elements into the real-world environment but also their interaction. In the MR experience, the user can see and interact with digital and physical objects (Tremosa, 2023). The most straightforward way to view a MR environment, therefore, is one in which real-world and virtual-world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum (Milgram and Kishmio, 1994). As mentioned before, XR would be an umbrella term that encompasses any sort of technology that alters reality by adding digital elements to the physical or real-world environment to any extent, as shown in Figure 2 – Extended Reality (XR) as an Umbrella Term (Tremosa, 2023).
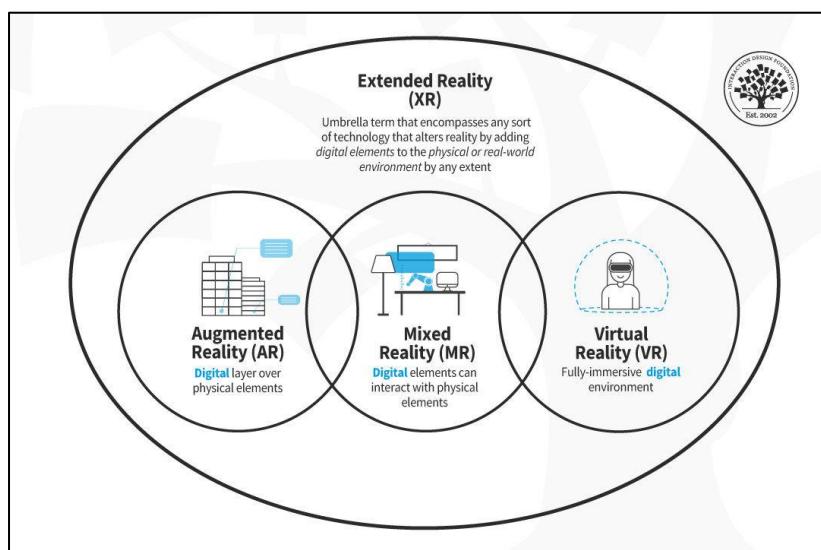
Figure 2 – Extended Reality (XR) as an Umbrella Term (Tremosa, 2023)

In recent years, AR has attracted significant attention from research institutions, universities, and businesses worldwide, resulting in numerous papers and scientific breakthroughs (Chen et al., 2019). These advancements have showcased AR's feasibility and innovation as a human-computer interaction technology. With the steady improvement in computing power, AR has transitioned from theoretical research to practical industry applications, acting as a bridge between the digital and real worlds. It offers people a fresh way to perceive and experience their surroundings and has been recognized as one of the top ten most promising technologies of the future by respected organizations like the American Times Weekly (Chen et al., 2019).

The utilization of an AR environment necessitates several components encompassing both hardware and software. Carmigniani & Furht (2011) mention the following main component:

1) Display: The display device, which can be a head-mounted display (HMD), handheld displays or spatial displays. This component allows users to perceive the augmented content superimposed onto the real world.
2) Input Devices: They include controllers, gloves, wristbands, or the touchscreen of a smart phone.
3) Tracking: Tracking devices consists of digital cameras and/or optical sensors, GPS, accelerometers. Solid state compasses, etc.
4) Computers: A powerful CPU and a good amount of RAM to process images. processor is essential for real-time processing and rendering in AR applications. It handles sensor data processing, camera tracking, computer vision tasks, and rendering of augmented content.

2.1.2. Challenges of AR

In recent years, AR has emerged as a transformative technology with the potential to reshape how individuals interact with the world around them. By blending virtual elements with the physical environment, AR opens up new realms of possibility in fields ranging from gaming and entertainment to education and industrial applications.

However, as explained by Ferrão (2023) in an interview regarding AR and Web-Application development, achieving accurate environment tracking and awareness remains a significant challenge that AR developers and researchers must overcome to fully harness the potential of this technology. While the potential of AR is vast, the challenges of environment tracking, and awareness are complex and multifaceted. Addressing these challenges requires collaboration between researchers, developers, and industry experts to advance the state of AR technology. Overcoming these hurdles will pave the way for a future where AR seamlessly integrates with our daily lives, enhancing our perception of reality and unlocking new possibilities across various domains (Ferrão, 2023).

Spatial Understanding and Mapping is one foremost challenge in AR by creating a precise and up-to-date digital representation of the physical world. This involves mapping physical spaces, recognizing objects, and understanding their spatial relationships. Building and maintaining such maps in real time requires sophisticated computer vision algorithms and sensors capable of capturing and interpreting the environment accurately. Any discrepancies between the virtual and real worlds can result in disjointed and disorienting user experiences. This process is commonly denominated as SLAM (Simultaneous

Localization and Mapping) (Durrant-Whyte and Bailey, 2006) it is the ingenious technology that empowers devices to navigate and understand their surroundings, creating a digital map while determining their own position in real time.

Real-world environments are dynamic and variable, subject to changes in lighting conditions, weather, and occlusions by objects and people. These variables can impact the effectiveness of AR systems that rely on stable and consistent tracking. Achieving robust performance across diverse environments requires algorithms that can adapt to changing conditions and maintain accurate tracking regardless of the challenges posed by the surroundings. (Ai et al., 2020)

Accurate depth perception is crucial for virtual objects to interact with the real world (Holynski and Kopf, 2018). AR systems need to accurately identify the relative positions of objects, people, and surfaces to ensure proper occlusion – the ability of virtual objects to be hidden behind real objects when appropriate. Ensuring consistent occlusion and depth perception is complex, as it involves integrating data from multiple sensors and accurately interpreting the spatial relationships between objects.

For AR to be truly immersive, it needs to respond in real-time to user interactions and changes in the environment. Achieving low-latency interactions between the physical and virtual worlds is vital to creating a seamless and believable experience. This requires powerful processing capabilities, optimized algorithms, and efficient communication between sensors, processing units, and display devices.

AR systems gather and process data about the environment and users, privacy concerns come to the forefront. (Lehman et al., 2020) Capturing and storing information about physical spaces and potentially identifiable individuals raises questions about data security and user consent. Striking the right balance between providing useful AR experiences and respecting user privacy is a challenge that developers and policymakers must navigate.

2.1.3. Modern AR

The future of AR technology is promising and poised for significant advancements in the next few years, as highlighted in the research by Chen et al. (2019). While mobile devices may not offer the same level of immersion as head-mounted displays, they enjoy widespread popularity among users. The introduction and popularization of development platforms like ARKit and ARCore have facilitated the technical combination of augmented reality and smart mobile devices. The future development of AR is anticipated to be enriched by smart wearable devices, which have the potential to fully leverage the advantages of augmented reality technology. This convergence is envisioned to create a more realistic integration world for human beings, enabling natural and seamless interactions with digital systems (Chen et al., 2019).

On the topic of novel AR techniques, Fanini et al. (2021) introduced one known as temporal lensing, which operates through local, volumetric manipulation of time within a virtual 3D space. Unlike conventional 2D see-through interactive lenses, this approach creates immerse AR sessions to offer a more powerful 3D tool for CH (Cultural Heritage) scenarios, enabling interactive and expressive discovery experiences for users. Notably, the implementation of this technique capitalizes on the potential of the web and its recent standards, facilitating the presentation and communication of different temporal layers through different interaction models, without requiring additional software installations.

It is important to highlight the utilization of a significant API in this research known as WebXR, this API is a freely accessible tool that empowers developers to create immersive XR environments in web applications. The results of their study demonstrated the technique's effectiveness in virtual restoration, by re-establishing formal integrity and revealing possible original appearances, while retaining recognizability of the current state of conservation, as shown in the following Figure 3.

Figure 3 – Temporal Lensing concept showed through original base scene (A), 7.5 m radius (B) and 26.5 m radius (C) (Fanini et al., 2021)

Furthermore, the temporal lensing technique is adaptable for implementation in other desktop game engines like Unreal Engine 4 and Unity, offering a user-friendly interaction model for high-fidelity real-time 3D applications that involve multi-temporal CH representations. This adaptability also paves the way for its use in collaborative scenarios, such as videogames, where multiple users on a network collaboratively explore and discover given scenarios. The future development of the temporal lensing technique holds the promise of revolutionizing how users interact with virtual 3D spaces, providing a powerful and immersive tool for exploring cultural heritage and unlocking new possibilities for engagement and learning in the domain of cultural preservation and heritage (Fanini et al., 2021).

Building upon the promising prospects of the WebXR technology, Greenway et al. (2023) developed a VR digital environment to serve as a recovery support package for head and neck cancer (HNC) patients, serving to meet their information needs and facilitate self-management. The research culminated in the creation of a WebXR platform known as the 'recovery' package, immersing patients in a virtual reality experience within a simulated room where they could access targeted resources and specific learning materials relevant to their cancer journey.

Figure 4 – Screenshots from VR experience to support head and neck cancer patients (Greenway et al., 2023)

The study's findings underscored the feasibility and efficacy of utilizing WebXR technology as a viable means of providing self-management support to HNC patients. By enabling patients to immerse themselves in a virtual environment and interactively engage with tailored content, WebXR facilitated a sense of ownership over their health journey. The interactive and personalized nature of the WebXR experience held great promise, offering a complementary and supportive forum for patients in clinical cancer care and rehabilitation environments. Looking ahead, the future developments in WebXR technology hold immense potential for the integration of interactive and tailored support in healthcare settings. As WebXR continues to evolve and advance, it could prove instrumental in addressing the multifaceted challenges faced by patients, enhancing their self-esteem, and empowering them to navigate their health journey with greater confidence and control (Greenway et al., 2023).

Google's ARCore stands as an example of a modern augmented reality developer platform, that provides developers and creators alike with simple yet powerful tools to build world-scale and room-scale immersive experiences (Silva, 2023). In an impactful collaboration, ARCore partnered with the Singapore Tourism Board to harness Google's novel Geospatial Creator within Unity, fashioning an immersive augmented reality guided tour, as shown in Figure 5. Geospatial Creator, powered by ARCore and Google Maps Platform, empowers developers and creators alike to visualize, build, and launch robust and engaging 3D digital content in real world locations through Photorealistic 3D Tiles. Everything you create in Geospatial Creator can be experienced in the physical world through real time localization and real world augmentation ("Geospatial Creator | ARCore," n.d.).
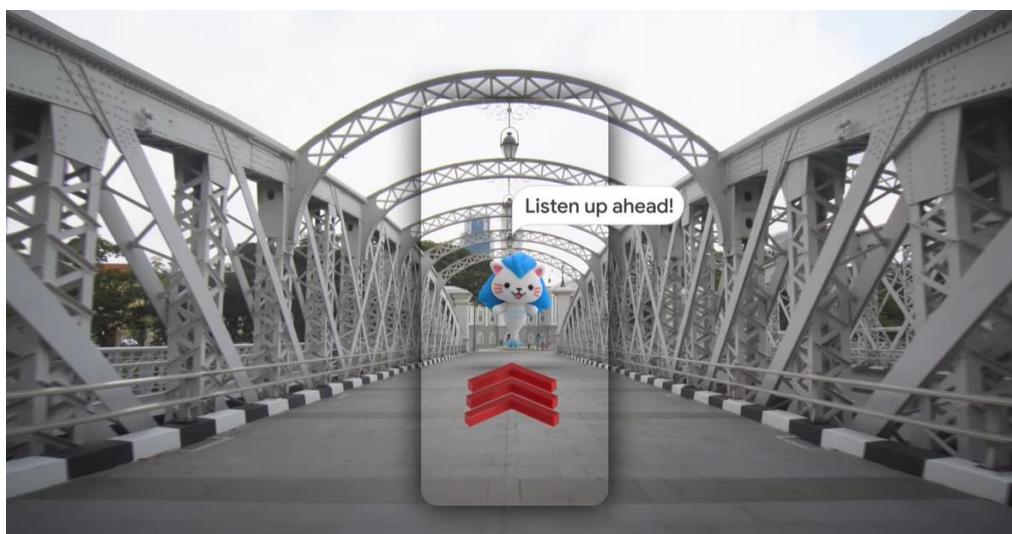
Figure 5 – AR city-guide created through Google's Geospatial Creator (*Make the world your adventure with Singapore Tourism Board*, 2023)

On June 5th of 2023, Apple unveiled its MR headset called the Apple Vision Pro. This device utilizes eye tracking and hand gestures through the use of multiple LEDs, infrared cameras, and high-resolution cameras to deliver extremely precise head and hand tracking and real-time 3D mapping, eliminating the need for physical controllers such as keyboards or touch screens. Waisberg, Ong, Masalkhi, Zaman, Sarker, and Tavakkoli (2023) explained how the capabilities of this technology can be utilized for diverse purposes, including but not limited to medical and surgical education, and remote medical consultations. Some mentioned examples include "…surgeons can use immersive virtual environments

to practice their surgical skills, in a secure and controlled environment, ultimately leading to better patient outcomes." And "These devices can help individuals with low vision navigate their surroundings, read text, and recognize objects."
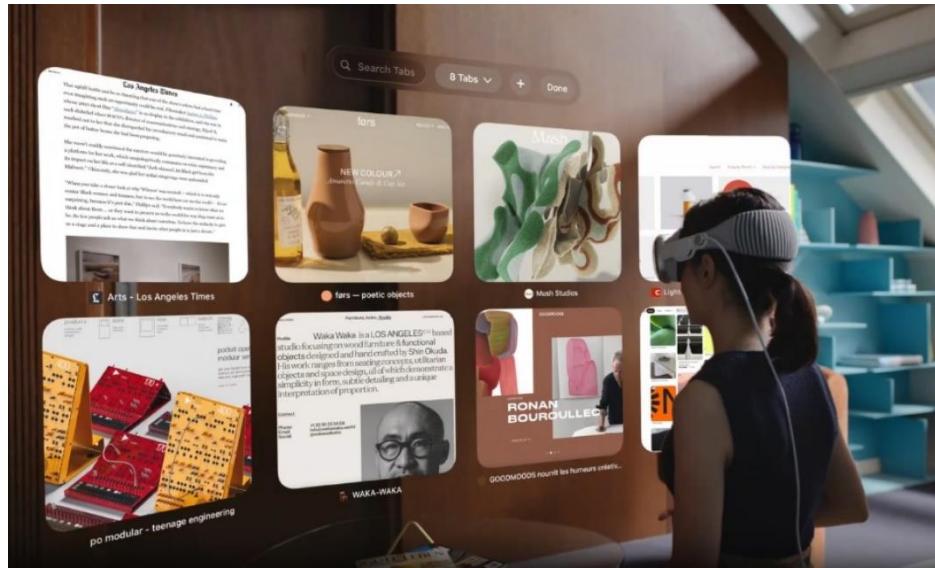
Figure 6 – Apple Vision Pro using AR to blend digital content with physical space. (*Apple*, 2023)

2.2. ASSET MANAGEMENT, FACILITY MANAGEMENT, OPERATION & MAINTENANCE, AND BIM

2.2.1. Definitions

Building Information Modeling (BIM) is defined as a "a shared digital representation founded on open standards for interoperability". It enables information from all project phases to be stored in a single digital model and serves as a reliable knowledge resource throughout the facility's life cycle (Farghaly et al., 2018). BIM can incorporate information gathered using various technologies during planning, design, construction, and O&M phases (Farghaly et al., 2018).

Asset Management (AM) is the coordinated activities of an organization to realize value from assets throughout their entire lifecycle. Assets in the built environment undergo various stages, including strategic planning, design, engineering, development, documentation, construction, daily operation, maintenance, refurbishment, and end-of-life or recycling (ISO 55000, 2014).

AM measures the capacity and ability of an asset to achieve its objectives. An asset can be an item, equipment, space, or any entity that generates financial or nonfinancial value for the organization. It encompasses resources, processes, and technologies to improve and facilitate the delivery of AM plans and asset activities (Farghaly et al., 2018). By transforming business objectives into asset-related decisions, AM aids in financial decision-making, short-term and long-term planning, and generating scheduled work orders.

Facility Management (FM) is a crucial discipline that has evolved with the changing business landscape and the influence of information technology (Alexander, 1994). It encompasses coordinated activities

aimed at efficiently managing and optimizing assets and services within an organization to support its primary activities (EN 15221-1, 2006). These assets, which include buildings, equipment, spaces, and services, go through various stages in their lifecycle, such as strategic planning, design, construction, daily operation, maintenance, and end-of-life or recycle (ISO 55000, 2014).

The main objective of FM is to realize value from assets throughout their lifecycle (ISO 55000, 2014). By effectively coordinating these assets and services, FM enables organizations to act proactively, meet requirements, and optimize costs and performance. FM practices involve integrating and coordinating all required support services while ensuring clear and transparent communication between the demand side and the supply side. This is achieved through dedicated persons acting as single points of contact for all services defined in a Facility Management agreement. Additionally, FM encourages the most effective use of synergies among different services, leading to improved performance and reduced costs (EN 15221-1, 2006).

The emergence of facilities management has been driven by a shift towards a more dynamic business environment and the recognition of the importance of knowledge workers and information technology. This movement aims to improve the management of workplaces, inspiring people to give their best, supporting their effectiveness, and positively contributing to economic growth and organizational success (Alexander, 1994).

Overall, Facility Management plays a vital role in optimizing assets and services within an organization, ensuring smooth operations, and contributing to its sustainable growth. In Figure 7 by Caputi (2023) provides a comprehensive overview of the broad scope of Facility Management, categorizing various services involved in the process.


Figure 7 – Scope of Facility Management (Caputi, 2023)

AM and FM are overlapping disciplines often used interchangeably, despite differences in their approach. While FM primarily concentrates on the infrastructure and building sectors, AM has a broader

application field. Both disciplines have established their own standards, specifications, and language of preferred terms (Guillen et al., 2016). Figure 8 visually illustrates the relationship between AM, FM, and O&M (Operation and Maintenance), providing a clear understanding of their interconnections.

Figure 8 – Relationship between AM, FM, and O&M (Guillen et al., 2016)

O&M are the main aspect to be focused on in facilities management because it is the major activity in sustaining the buildings and to keep it as a valuable asset and functioning building. The only way to achieve this is by properly operating and maintaining the facilities (Hapira et al., 2020).

All this explains the conceptual size and scope of FM, covering everything from real estate and financial management to maintenance and cleaning, even considered a consolidated profession in the building concept (Guillen et al., 2016). Based on this, FM was selected as the main concept to use in this research, as it is the most widely used concept in the BIM community or building industry. Consequently, recognizing the importance of FM in managing facilities effectively, it becomes evident that the effective management of FM information is a critical factor for success.

The operation phase of facility management presents multiple complexities, necessitating effective FM practices to ensure optimal facility performance. One of the challenges encountered in FM is the limitations of 2D graphics when attempting to depict maintenance services (Chen and Luo, 2014). Traditional 2D representations may not adequately capture the intricate details and spatial relationships required for facility maintenance planning and execution.

The operation phase of a facility is also a critical period where the largest fraction of expenses is incurred, making cost predictability a vital concern for facility managers (Aziz et al., 2016). Effective FM becomes instrumental in optimizing operational costs while ensuring that the facility's functionality and value are sustained throughout its life-cycle. By integrating vast and updated information from various systems and stakeholders, facility managers gain a comprehensive view of the facility's status, enabling them to proactively address maintenance tasks and allocate resources efficiently (Kazado et al., 2019). Leveraging advanced technologies like the Internet of Things (IoT) sensors further enhances

FM by providing real-time data on equipment conditions, enabling predictive maintenance strategies that reduce downtime and minimize costly repairs.

2.2.2. Empowering AM/FM/OM through BIM

Effective FM requires robust information management to support its multidisciplinary activities (Becerik-Gerber et al., 2012). While some existing FM information systems partially address these needs, the integration of BIM opens up promising possibilities for enhancing FM practices through its visualization, analysis, and control functionalities. Researchers Becerik-Gerber, Jazizadeh, Li, and Calis (2012) highlighted how BIM enhances various FM practices:

- Locating Building Components: 3D BIM models enable precise equipment location, reducing costs and paper dependency. Navigation tools and mobile devices enhance the process, while linking BIM and FM databases aids in effective equipment maintenance.
- Facilitating Real-Time Data Access: BIM serves as a unified data access point across databases, streamlining tasks like maintenance. It enables personnel to select objects and retrieve FM system data, enhancing efficiency and informed decisions.
- Visualization and Marketing: BIM enhances visualization, aiding decision-making, training, and marketing. Its 3D interface, material texture, and lighting features enhance space visualization, aiding analyses and presentations.
- Checking Maintainability: BIM fosters a closed loop between design, construction, and FM operations, using historical data to support FM processes. It shapes new construction, reduces risks, and automates maintainability checks using geometric and semantic data.
- Creating Digital Assets: BIM improves the creation of digital assets by standardizing labeling, accurate BIM model data, and timely document digitalization. These assets encompass equipment, systems, data, and documents crucial for effective facility management.
- Space Management: BIM visually represents spaces and attributes, identifying underutilized spaces, streamlining analysis, and managing moves. It aids identification, assignment, control of spaces/assets, and asset movement tracking.

Integrating BIM-FM data offers a high-quality database, leading to improved return on investment, cost reduction, enhanced decision-making, minimized financial losses, and improved health and safety. BIM offers significant functionalities like visualization, analysis, and control, highlighting how they empower FM professionals with valuable insights for efficient operations and data-driven decision-making during the FM phase (Farghaly et al., 2018).

Moreover, delving into the integration of BIM-FM data and its benefits highlights the crucial role of the concept of Level of Development (LOD) in enhancing facility management practices. LOD refers to a numeric scale ranging from 100 to 500, encompassing both graphical detail and general information, such as materials and numerical data (Leite et al., 2011).

However, Bolpagni (2022) highlighted the need for a more refined approach, which leaded to the concept of Level of Information Need. Unlike a numerical scale, Level of Information Need represents a framework to define information requirements based on necessity, efficiently providing the right information to the relevant stakeholders at the appropriate time while avoiding information waste. This

concept enables automatic compliance checking and ensures that the required level of information is readily available for comprehensive analyses and informed decision-making during the design and construction phases (Bolpagni, 2022). The process to define a Level of Information Need is defined in the ISO 19650-1 (2019) with the idea that "The level of information need of each information deliverable should be determined according to its purpose".

Building upon the significance of Level of Information Need in BIM-FM integration, asset management studies have underscored the critical importance of quality information in successful asset management standards implementation and effective decision-making. Effective information management not only enhances data quality but also improves service quality and fosters cooperative work among stakeholders. Moreover, it enables the provision of coordinated services between organizations, equips employees to make better decisions, and facilitates faster and more economical system development. To harness the full potential of asset information, organizations must establish a streamlined process to identify and document essential information in a unified database accessible across the entire organization (Gandini Panegossi et al., 2022).

Adequate Asset Information Management serves as a valuable resource in two main ways (Caputi, 2023). First, it assists individuals on their asset management process by providing clarity on the discipline, guiding them to discover more information, and outlining the next steps to take. Second, it supports organizations in making informed decisions about adopting asset management practices or enhancing their existing asset management capabilities. The ISO (International Organization for Standardization) is an independent, non-governmental international organization that develops and publishes standards like ISO 55000 (2014), ISO 55001 (2014), and ISO 55002 (2018), these three specifically go over the concepts of asset management, the requirements, and guidelines for adequate information management.

These ISO standards emphasize the significance of information management within an asset management system, which comprises interconnected and interacting aspects of an organization. This system is designed to develop the asset management policy, objectives, and necessary processes for achieving those objectives. Within the ISO-defined information management framework, each party involved in the process (e.g., clients, designers, contractors, and sub-contractors) must take responsibility for their respective roles. Simply requesting a "BIM project" without comprehensive information management might not meet ISO requirements, potentially leading to missed benefits and ineffective asset management practices (ISO 55000, 2014).

The use of BIMFM offers numerous benefits, one of the biggest ones is combining three-dimensional visualization to locate components, enabling real-time data access, checking maintainability, and automating digital asset creation (Becerik-Gerber et al., 2012). Traditional 2D graphics can limit the depiction of maintenance services. BIMFM overcomes this challenge by providing maintenance staff with access to 3D BIM models, allowing for efficient updates of maintenance records in a digital format (Chen and Luo, 2014).

A significant advancement in FM is the concept of digital twins, a dynamic model continuously evolving alongside its physical counterpart based on real-time data collection, allowing prediction of future states. Digital twins consist of three main components: the physical entity, virtual entity, and

bidirectional connectivity between them (Eneyew et al., 2022). In the context of FM, the usage of digital twins offers several benefits. Firstly, digital twins provide intuitive access to information, simplifying the process of locating and accessing relevant data, leading to faster data collection, georeferencing, and integration with ERP (Enterprise Resource Planning) systems. Secondly, the adoption of digital twins results in efficiency gains, facilitated by unified access to asset information through integrated systems and databases with bi-directional communication to ERP systems. Lastly, digital twins help avoid mistakes by complementing traditional "folder-based" databases typically used in ERP systems with additional information such as geographic position and technical details (Caputi, 2023).

The adoption of digital twins in FM is just one example of the transformative impact of the fourth industrial revolution, known as Industry 4.0. This ongoing digital transformation, characterized by the digitization and intelligentization of manufacturing processes, is reshaping industries and driving fundamental changes in the way individuals live and work (Ghobakhloo, 2020).

Industry 4.0 represents a new level of organization and control over the entire value chain of product lifecycles, catering to increasingly individualized customer requirements. This revolution (as shown in Figure 9) is marked by the integration of technologies such as the Internet of Things, Industrial Internet, Smart Manufacturing, and Cloud-based Manufacturing, allowing industries to shift from mass production to customized production and enhancing overall productivity (Vaidya et al., 2018). As FM adopts digital twins and embraces the principles of Industry 4.0, it stands to benefit from improved efficiency, streamlined processes, and a more sustainable approach to facility management.
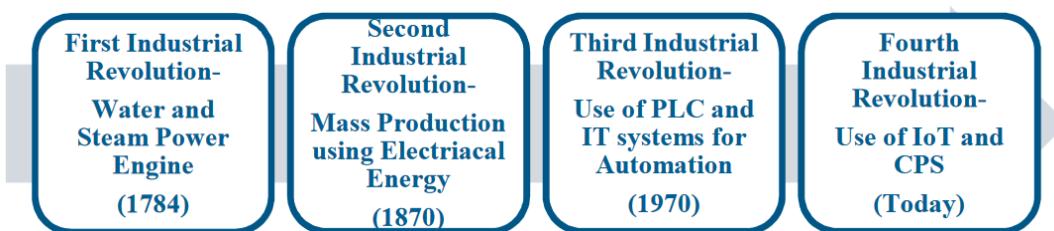

Figure 9 – The four Industrial Revolutions (Vaidya et al., 2018)

2.2.3. BIM Interoperability

Achieving interoperability also stands as a critical challenge when utilizing BIM data for facility management (Farghaly et al., 2018). The entire theoretical framework of BIM's application in FM relies on the assumption that data can exchange between different software programs. Traditionally, one-to-one interactions among heterogeneous software have resulted in numerous data interfaces, diverse formats, and inefficient collaboration. To address this, data sharing and exchange emerge as pivotal factors for ensuring interoperability and fostering collaboration throughout the building lifecycle. Given the involvement of multiple disciplines, the need for data sharing and exchange among diverse software tools becomes inevitable, necessitating a standardized and robust data format.

As a solution, an object-oriented data model called IFC (Industry Foundation Classes) was developed to facilitate data sharing and exchange. IFC provides very rich data structures covering almost all aspects

of built facilities. In 2013, the data format was adopted as an ISO standard and it now forms the basis for many national guidelines that stipulate the implementation of Open BIM (Borrmann et al., 2018).

Illustrated in Figure 10, The IFC schema serves as a medium for bidirectional data exchange, further enhancing the collaboration potential among diverse software applications. Multiple versions have been released of IFC, IFC 2×3 and IFC 4 are the two current versions. Although IFC2X3 was released earlier, it is the most widely used version at present and is likely to remain so in the near future. This delay is partly because key BIM software requires a significant amount of time to implement a new version. In addition, many projects underway at present employ BIM execution plans that specify IFC2X3 as the preferred exchange format (Bao et al., 2022). For these reasons, this study utilizes the IFC2X3 (.ifc files) from the BIM software application.


(a) Traditional method   (b) BIM-based method
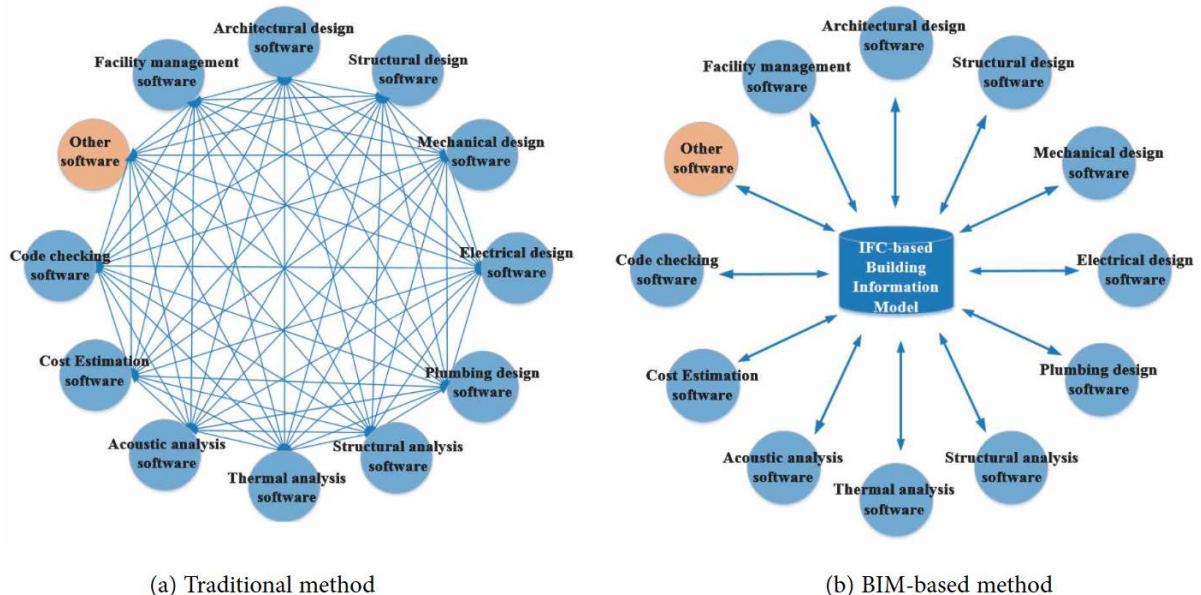
Figure 10 – Data Interoperability between various software tools (Huahui and Deng, 2018)

2.3.   INTEGRATION OF AR AND BIM

2.3.1.   General Cases of AR and BIM

In this section, this research will explore contemporary instances where AR integrates with the construction industry and BIM. Machado & Vilela, (2020) conducted a study to assess the potential of AR in conjunction with BIM and its applications in the construction industry. Notable findings include that 48% of the examined papers focused on building site inspection. Fiducial markers, GIS/GPS, laser scanners, and photogrammetry emerged as key methods for automated data collection on construction progress. Machado & Vilela (2020) conclude by highlighting that the integration of AR and BIM addresses information processing challenges and enhances construction management practices.

Figure 11 illustrates the primary domains of investigation within the research, highlighting a substantial potential for the integration of AR with BIM modeling. This integration offers significant applicability in aiding operations inspection, building maintenance, infrastructure management, and installation assemblies. By incorporating AR within these domains, users can engage intuitively with the

technology, fostering immersive experiences within the BIM models. Moreover, this integration contributes to a faster response time in addressing potential solutions for retrofitting tasks at construction sites (Machado and Vilela, 2020).
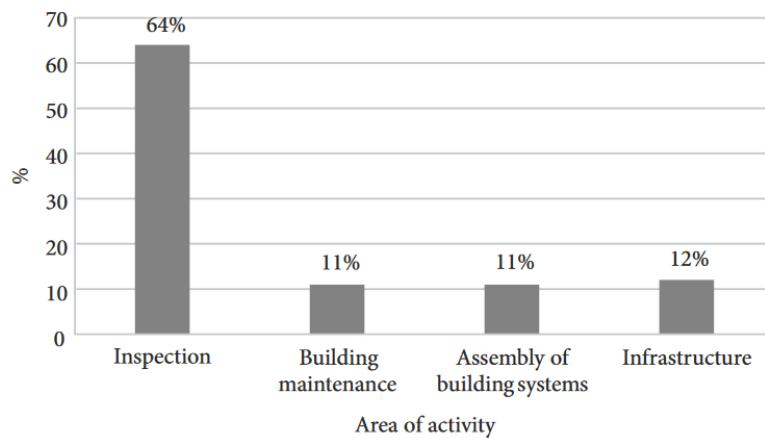

Figure 11 – Areas of activity researched (Machado and Vilela, 2020)

Schranz, Urban, and Gerger (2021) addressed an equally intriguing topic, emphasizing the often-overlooked significance of the submission process within the BIM project cycle, despite its substantial influence on building projects. Their research highlighted the considerable potential of combining BIM and AR within the building submission process. AR technology can play a crucial role in aiding building authorities in evaluating compliance with building regulations. Moreover, AR facilitates the visualization of project impacts for non-experts involved, enabling more informed decision-making. While advocating for an openBIM submission process utilizing IFC, it is noteworthy that the AR scene is created using the Unity platform, necessitating the conversion of the IFC format into JSON (JavaScript Object Notation) or OBJ format for effective integration (Schranz et al., 2021).

AR and VR technologies hold immense promise for safety training within the construction industry. By simulating potentially hazardous scenarios, these technologies provide an interactive platform for workers to undergo safety training. In 2022, Sidani, Poças, and Soeiro conducted a study at the University of Porto, showcasing the substantial potential of VR and AR in enhancing risk visualization for both workers and students. VR envelops users in a virtual environment, while AR overlays additional information onto their real-world surroundings. This research underscores the pivotal role that AR/VR can play in elevating safety protocols and heightening awareness across the construction domain. Notably, the study involved six authors who predominantly developed their BIM Models in Revit. Microsoft XNA Game Studio, Unreal Engine, 3D Unity, and Navisworks, were mentioned as the game engines used to construct the AR/VR environments. Additionally, one author adopted an Open Format approach, sharing an HTML file for viewing through an Adobe Flash player or a web browser (Sidani et al., 2022).

A novel open format approach to enhancing safety training in construction companies was explored by Bao, et al. (2022) at the University of Seoul, focusing on a VR virtual environment. This innovative framework centered on BIM models in the IFC format, harnessing WebXR and IFC.js to create an immersive web-accessible environment. This interactive virtual space facilitated both individual and

collaborative training, enabling multiple users to share knowledge within a unified digital realm. A distinctive contribution of this research lies in the development of a cross-platform framework (CPVR) rooted in IFC and WebXR, offering potential BIM-related benefits. While many studies employ game engine software such as Unity3D or Unreal Engine for virtual environments, they often necessitate plugins to link with BIM software, which can hinder IFC file format utilization and lead to data loss during conversions. In contrast, the CPVR framework operates on diverse platforms (e.g., Windows OS, Mac OS, Android, and iOS), serving as a tool for safety training among workers. The proposed framework encompasses several modules, visually depicted in Figure 12 (Bao et al., 2022).
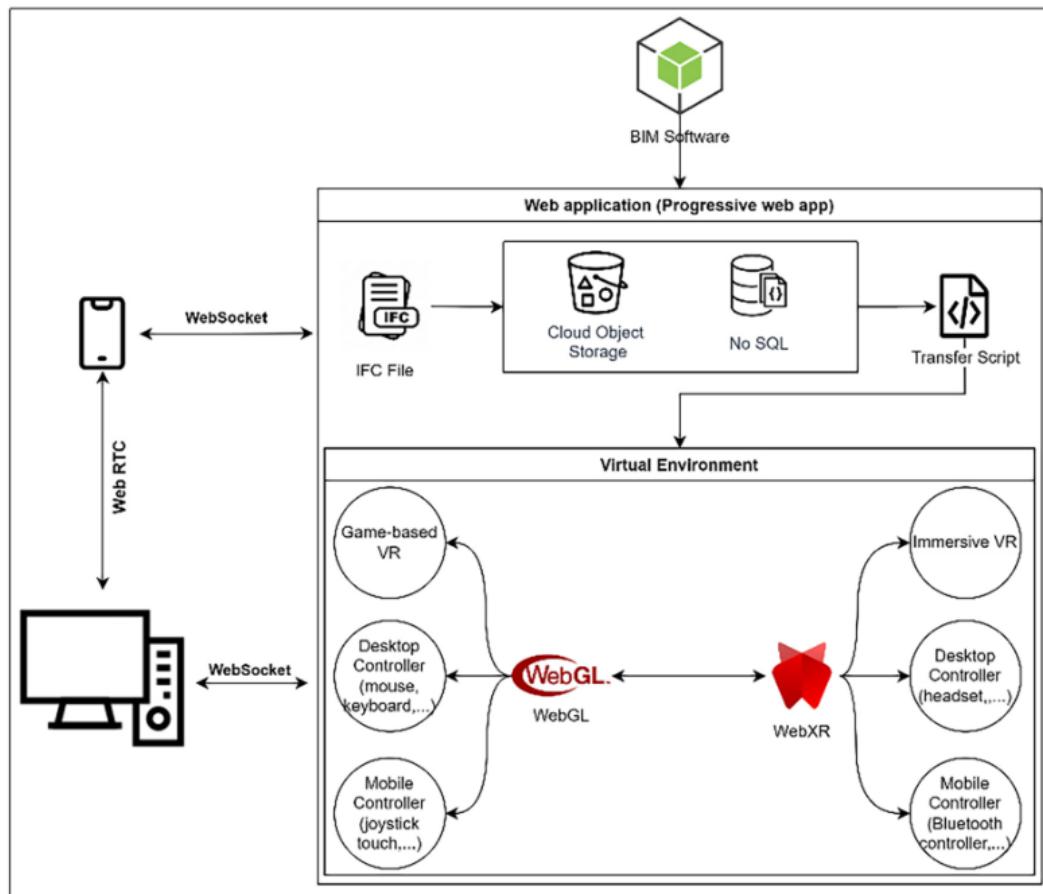

Figure 12 – Structure used in CPVR framework (Bao et al., 2022)

This study explains the role of the IFC Script in enabling data transfer from an IFC file to WebXR, eliminating the need for intermediate file format conversions. The utilization of WebGL and WebXR offers versatile avenues for virtual environment interaction. Notably, users can engage with the virtual experience using various devices, such as head-mounted displays (HMDs), Google Cardboard, and Bluetooth controllers for immersive VR. Alternatively, game-based VR can be experienced through conventional input devices like keyboards, mice, touchscreens, and game controllers (Bao et al., 2022).

Moreover, Nandavar, Petzold, Nassif and Schubert (2018) embarked on a research endeavor to forge a vendor-neutral integration of BIM and VR with bidirectional data exchange. The central objective was to transcend VR's conventional role as a visualization tool and imbue it with collaborative capabilities within the BIM framework. The motivation behind this study stemmed from the intricate and repetitive

process of converting BIM models to Unity-compatible formats (such as FBX or OBJ), which not only engendered inefficiency but also led to the loss of critical BIM model information. Furthermore, the absence of feedback from the VR system back to the BIM model presented challenges in documenting the outcomes of planning sessions conducted in the VR realm (Nandavar et al., 2018).

In addition, the researchers conducted an extensive review of prevailing literature concerning the integration of BIM and VR. This exploration aimed to discern primary applications, which encompassed spatial orientation, technical communication, safety assessments, and emergency simulations. Their inquiry revealed two predominant strategies for BIM-VR integration: the infusion of BIM data into game engines and the employment of tailored pipelines to render BIM in the VR domain. For their investigation, the Unity Game engine emerged as the selected VR endpoint for the pipeline, owing to its wealth of VR interaction authoring resources and robust developmental support for HTC VIVE (Nandavar et al., 2018).

Another approach involves FabStation-STEEL, an augmented reality steel software developed by Eterio Realities Inc. This software integrates 3D assets into workers' tasks. Using iPad Pro and Microsoft HoloLens 2, it allows users to overlay Tekla or SDS2 models with precision up to 1.60 mm. A distinctive feature permits intricate assembly overlays on detailers' 3D models, as depicted in Figure 13. The outcome includes significant error reduction on-site, coupled with notable efficiency improvement. Implementing less specialized personnel for inspections results in a remarkable 50% time reduction while achieving a substantial tenfold accuracy enhancement ("FabStation - STEEL," n.d.).
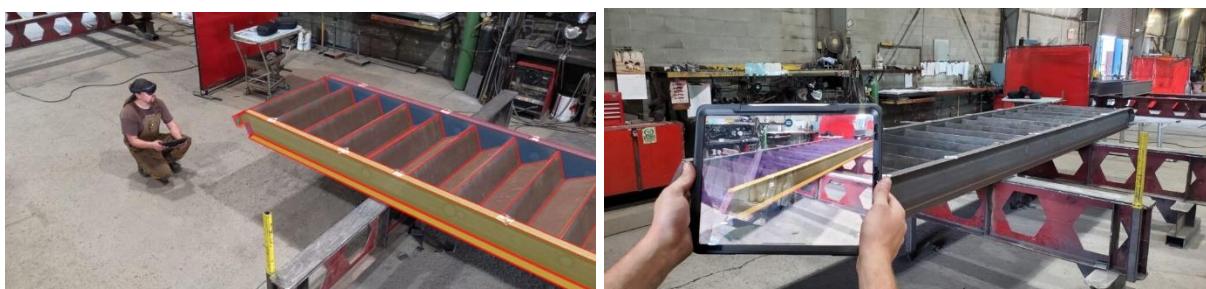

Figure 13 - FabStation-STEEL Augmented Reality Steel Software ("FabStation - STEEL," n.d.)

In the context of enhancing BIM-VR integration, AEC Magazine (2023) featured OpenSpace BIM+. This innovative solution effectively utilizes AR technology to streamline BIM workflows on construction sites. OpenSpace BIM+ complements OpenSpace Capture, serving as an add-on product that comprehensively documents construction sites and provides a suite of BIM analysis and coordination tools. The software facilitates model management, empowering site teams to operate within the BIM model and juxtapose it against the actual construction progress. OpenSpace BIM+'s versatility yields substantial advantages for the entire project team, facilitating tasks like progress monitoring, defect identification, on-site BIM data collection, quality control, and comprehensive project documentation. Additionally, it fosters enhanced communication, collaboration, and overall project efficiency across the construction process (AEC Magazine, 2023).

2.3.2. Specific Cases with FM

Matoseiro, Rodrigues, and Pedro da Silva (2023) conducted a significant study aimed at enhancing the adoption of BIM within the AECO (Architecture, Engineering, Construction, and Operation) sector, focusing specifically on its integration in facility management. They achieved this by creating an immersive VR interface that combines BIM models with natural user interactions (NUIs). The main objective was to make BIM more user-friendly and accessible for professionals engaged in facility management tasks. The system they proposed consists of two core components and an additional module.

The Python Module was designed to smoothly incorporate BIM models into a game engine, ensuring consistent model definitions and geometry. A key feature is its automated process to synchronize changes made within the immersive VR environment back to the original IFC file. In parallel, the Unity Module introduces an immersive VR interface for easy interaction with BIM data using natural gestures and voice commands. The backbone of the system's effectiveness is the IFC schema, which facilitates data exchange and interoperability. Furthermore, the system includes a dedicated validation module to verify any modifications to IFC files (Matoseiro Dinis et al., 2023).

The significance of this framework is highlighted by its validation within the AECO sector. To assess this, extensive interviews were conducted involving 31 professionals, yielding insights from a total of 62 interviews. The findings showed that while VR technology is often associated with entertainment, its potential in maintenance contexts remains largely unrecognized. However, respondents showed significant interest in the proposed VR solution for facility management, recognizing its potential to integrate into their workflow and enhance work processes. This is particularly noteworthy as the solution has the potential to simplify daily tasks, improve decision-making, and enhance facility management efficiency (Matoseiro Dinis et al., 2023). Looking ahead, a framework like this could play a crucial role in establishing a stronger connection with an immersive digital twin interface, offering transformative possibilities for refining planning accuracy, optimizing training, and elevating facility management practices.

Another BIM-centric AR workflow was conceptualized by (Hajji et al., 2022), showcasing the utilization of BIM and AR capabilities, particularly in fostering interactive and intuitive management within AECO projects. This innovative approach materialized in the form of the "EasyBIM" application, which facilitates access and engagement with a BIM model. The application boasts a spectrum of functionalities encompassing measurement, data retrieval, collaborative features, visualization, and the assimilation of sensor-derived information. Crafted for mobile platforms, including tablets and smartphones, this application employs an IFC file as input and orchestrates the AR environment using Unity 3D (Hajji et al., 2022).

Encouraging test results underscore the integration of EasyBIM with diverse BIM contexts, such as marketing, collaboration, site monitoring, and facility management, among others. Notably, within Facility Management, EasyBIM showcases an innovative facet by facilitating a direct linkage with an Internet of Things (IoT) system. This dynamic integration allows real-time visualization of sensor-derived data, thereby offering a novel dimension to information accessibility and comprehension. The utilization of AR technology proves invaluable in surmounting screen-related limitations, particularly

when dealing with multiple sensors. It is pertinent to note that while our approach presupposes data integration at the Google Drive database level, alternative methods exist for fusing IoT data into the BIM framework via open standards (Hajji et al., 2022).

Yigitbas, Nowosad, and Engels (2023) delved into the application of AR in the maintenance and operation phase, where VR is not a viable option as maintenance workers must perform tasks on-site in the real-world environment. The study identifies two primary uses of AR in this context. Firstly, AR aids in navigation, by locating failed assets and providing users with guided paths directly to the problematic areas, as shown in Figure 14a. The other described use is task guidance, which include tasks like automatically detecting anomalies, highlighting the failed asset, and even showing maintenance workers information or animations for a step-by-step guide on how to do their tasks, as shown in Figure 14b.

(a) **Navigation** (b) **Talk Guidance**
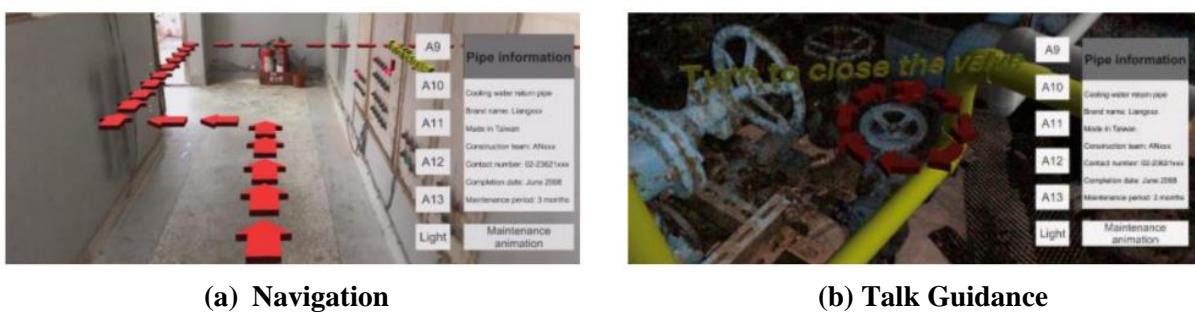
Figure 14 – BIM-Based AR Maintenance System (BARMS) (Diao and Shih, 2019)

These two Figures come from the intelligent instruction framework called Building information modeling-based Augmented Reality Maintenance System (BARMS), a smartphone-based platform running on ARKit, using the AR Software Development Kit (SDK) for visualization, and used Unity to create the AR scene, which is considered one of the best platforms for creation and operation real-time 3D content. Even though BARMS is not an open format approach, it was considered a successful application with confirmed facility management integration (Diao and Shih, 2019).

2.4. INFORMATION SYSTEM FOR WEB-BASED APPLICATIONS

2.4.1. Web Application Structure

The architecture of web applications for AR/VR and BIM integration has been a subject of investigation in recent research. Web-based technologies play a crucial role in facilitating data viewing immersive and interactive experiences through mobile and web environments.

Specifically, augmentations produced through AR content systems are naturally restricted to being disseminated through mobile devices, headsets, or other AR capable hardware. While this limitation does not hinder many of the use cases various AR applications are designed for, it critically excludes access for any readers who are not inclined to use AR capable devices when reading scientific articles (Ard et al., 2022).

People tend to think web-based applications are not as powerful as desktop software's, but the truth is that modern browser-based applications are performant and highly scalable (González, 2022), with the introduction of modern API that allow the browser to access advanced computational resources such as multi-core processing and graphics processing, web apps are now closer in performance to native applications. Associated with the ease of development and portability of web applications they became the default for developers.

Traditionally web application is split into two sections: the frontend and backend components. These play a distinct but interconnected roles in delivering a cohesive user experience and handling the underlying functionality.

The frontend is responsible for designing and creating the user interface that users interact with. This includes the layout, visual elements, navigation, and overall look and feel of the application. UI designers and frontend developers work together to ensure a visually appealing and user-friendly interface. Developers ensure that the application works consistently across various web browsers and platforms. They address browser-specific quirks and implement solutions to maintain a uniform experience for all users. In a AR application the frontend takes care of environment perception, rendering of 3D elements, tracking and user interaction (Ferrão, 2023).

The backend manages the storage, retrieval, and manipulation of data. It interacts with databases or other data storage solutions to handle user accounts, content, transactions, and other application-related information. It also implements the core business logic of the application. It processes user requests, performs calculations, enforces rules, and orchestrates the interaction between different components to fulfil the application's functional requirements. The backend exposes APIs (Application Programming Interfaces) that frontend components use to communicate with the backend. APIs define how data is requested, sent, and received between the frontend and backend, allowing for effective data exchange (Ferrão, 2023).

An essential tool during the development and testing phase, is Webpack's 'webpack-dev-server'. This is a tool used to execute applications via a local development local server. This server effectively serves as the backend during testing, handling tasks like JS code compilation and asset management, such as images, models, and fonts, which are then delivered to the frontend ("DevServer - Webpack," n.d.).

The REST API (Representational State Transfer Application Programming Interface) is a set of rules that allows software applications to communicate with each other, by exchanging data through the internet. In the context of a web application, a REST API serves as a bridge between the frontend and the backend, enabling the frontend (user interface) to request and provide data to the backend (server), facilitating the functionality of the application (Fielding, 2000).

Object-oriented programming (OOP) is a powerful methodology employed in AR/VR and BIM app development, it focuses on using objects as fundamental components, allowing interaction between them. Unlike structured programming, which demands well-structured algorithms, OOP focuses on manipulating objects with functions and variables, enabling smoother interactions (Dzikrurobbi, 2019).

OOP is not just about coding; it is a way of solving problems. It encourages thinking in terms of objects, akin to real-world concepts. This approach simplifies development by aligning with natural thought

processes. OOP involves designing and using classes as essential building blocks for problem-solving. Inheritance and polymorphism are tools in OOP that make work faster and easier. Inheritance enables the creation of new classes using existing ones, saving the effort of starting from scratch. It is akin to building upon an existing foundation. Polymorphism facilitates the utilization of different classes in similar manners, enhancing code flexibility and ease of modification (Rahnev et al., 2014).

By enabling code reuse through inheritance and polymorphism, OOP enhances efficiency and maintainability. Inheritance allows creating new classes from existing ones, sharing attributes and methods, reducing code repetition. Abstract interfaces promote generality, aiding in creating multiple subclasses that share common traits. This method enhances software development for complex AR/VR and BIM apps (Rahnev et al., 2014).

2.4.2. Database

A database is a structured and organized collection of data that is stored, managed, and accessed electronically. It serves as a digital repository for storing various types of information, such as text, numbers, images, and more. Databases are designed to efficiently store, retrieve, update, and manage data, enabling users and applications to interact with information in a structured and meaningful way (Khan et al., 2023).

Database management is critical for the efficient content and BIM data. Databases can be accessed simultaneously by many users and allow for high throughput of data in connected applications, such as required for BIM applications. Databases can be categorized as structured or not structured (Khan et al., 2023). Structured databases typically use SQL as their main language and organize their data into tables with a well predetermined structure, in the other hand non-structured databases store data for which the data structure might not be known, usually they use a document-based approach in which each entry of the database might have its own structure, these are also known as a NoSQL database.

SQL (Structured Query Language) databases, also known as relational databases, follow a structured format where data is organized into tables with predefined columns and data types. SQL is a standardized language used to manage and manipulate data in these databases. Each table represents a distinct entity, and relationships between tables are established through keys, allowing for complex data modelling. SQL databases ensure data integrity, support transactions, and provide powerful querying capabilities through SQL commands (Hu et al., 2023).

NoSQL (Not Only SQL) databases offer a more flexible and schema-less approach to data storage and retrieval. These databases are designed to handle large volumes of unstructured or semi-structured data, making them suitable for applications where data types and structures vary widely. NoSQL databases are categorized into several types, including document stores, key-value stores, column-family stores, and graph databases. They excel at providing high scalability and performance in scenarios like big data processing, real-time analytics, and web applications.

Mapping IFC (Industry Foundation Classes) data into a database involves transforming the structured information from IFC files into a format that can be efficiently stored and queried within the chosen database system. This process is crucial for enabling effective management, analysis, and retrieval of building-related data. Both SQL and NoSQL databases can be used for this purpose,

IFC files are typically structured using a specific schema defined by the IFC standard. You'll need to extract relevant data from IFC files and transform it into the format expected. The IFC data includes relationships between entities (e.g., a wall connected to a door), establish these relationships within the database. Once the IFC data is mapped into the database, you can use SQL queries or database-specific query languages to retrieve specific information from the database (Ferrão, 2023).

2.4.3. Libraries and APIs

An API, which stands for Application Programming Interface, is a set of rules and protocols that enables different software applications to communicate and interact with each other. It defines how applications can request and exchange information, facilitating smooth integration and data exchange between different software systems. APIs are commonly used to access the functionality of remote services or platforms, like social media APIs for accessing user data or payment gateway APIs for handling online transactions. They play a vital role in modern software development by allowing developers to use the capabilities of other applications and services without needing to know how they work behind the scenes (Fielding, 2000).

In the programming context, a library refers to a digital library, which is a collection of pre-written code and functions that developers can use to simplify and speed up the development process. These libraries contain reusable code and modules that handle common tasks like managing data structures, performing mathematical operations, creating user interface components, or interacting with external services using APIs. These digital libraries are widely used by developers to streamline their development, adhere to best practices, and ensure a more efficient and robust application (Duckett, 2014).

IFC.js is an open-source JavaScript library, that plays a pivotal role in the realm of BIM integration by facilitating the infusion of IFC data into web applications, presenting a significant advancement for the AEC industry. Through IFC.js, developers gain the ability to parse, read, and interpret IFC files, enabling them to access and incorporate BIM data directly into their web-based projects. IFC.js also allows web developers to craft dynamic 3D visualization tools, collaborative BIM viewers, and various other web applications that harness BIM data. An essential JavaScript library is web-ifc, which is an open-source library that provides tools for parsing IFC files directly in web applications, at native speeds. web-ifc is part of the ifc.js project, which aims to lower the threshold for developing open BIM applications. This integration enhances project coordination and communication within the industry, fostering better understanding and collaboration among stakeholders ("IFC.js," n.d.).

WebGL (Web Graphics Library) is a JavaScript API that enables the creation of high-performance 3D graphics directly within web browsers, eliminating the need for additional plugins. By leveraging the power of the Graphics Processing Unit (GPU), WebGL allows developers to build interactive 3D animations and graphics integrated with HTML5, CSS, and JavaScript. It is based on the widely-used OpenGL ES standard, bringing hardware-accelerated 3D rendering capabilities to web environments. This technology finds application in diverse areas, including virtual reality, data visualization, simulations, and interactive presentations, making it an essential tool for crafting immersive web-based applications and games. Supported by major web browsers like Google Chrome, Mozilla Firefox, Microsoft Edge, and Safari, WebGL enhances the web experience by delivering smooth and responsive

visual content. It is important, however, to account for scenarios where WebGL might not be supported or disabled, offering fallback solutions to ensure accessibility across a broad audience ("WebGL," n.d.).

One noteworthy library is three.JS, it offers a simple and structured API that encapsulates the original WebGL functionalities, providing a range of 3D functions, allowing the creation of cameras, lights, materials, and objects.

One notable library is Three.js. While it is important to note that Three.js frequently utilizes WebGL for rendering 3D graphics, it simplifies the process significantly. WebGL operates at a very low level, primarily dealing with points, lines, and triangles. However, to achieve meaningful results with WebGL, considerable coding is typically necessary. This is where Three.js comes into play. It manages various aspects like scenes, lighting, shadows, materials, textures, and 3D mathematics—areas that would require extensive manual coding when using WebGL directly (Threejs.org, n.d.). With the enhanced computing power of JavaScript the 3D effects based on JavaScript have distinct advantages, both in visual appeal and performance, ultimately enhancing user experience. Utilizing Three.JS reduces the workload when compared to other technologies. Its strengths include being open-source, user-friendly, and highly efficient (Wang et al., 2016).

Three.js serves as a powerful tool for crafting 3D graphics and facilitating AR experiences. Through a JavaScript-based interface, it empowers developers to load, manipulate, and animate 3D models, apply textures, and implement lighting effects. In the realm of AR, Three.js assumes a crucial role in seamlessly integrating AR elements into web applications. It offers essential features like marker-based tracking, object recognition, and the ability to overlay 3D content onto the real world (Threejs.org, n.d.). Transitioning into a visual representation, a typical Three.js application involves the creation of interconnected objects, forming a structured framework. Refer to Figure 15 for a visual depiction of this concept.
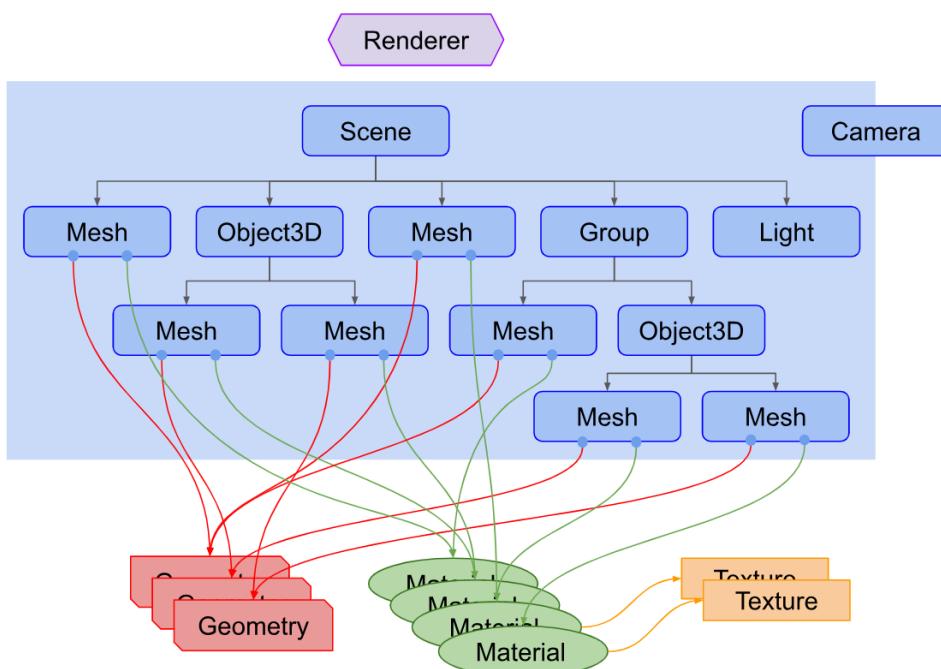
Figure 15 - Diagram of a Small Three.js App (Threejs.org, n.d.)

These interconnected objects create a structured framework for constructing and rendering 3D scenes in Three.js. Objects depicted in the aforementioned diagram are defined as follows (Threejs.org, n.d.).

1. Renderer: The central component that renders the 3D scene as a 2D image onto a canvas. It processes the scene and camera through a frustum to produce the final output.
2. Scenegraph: A tree-like structure composed of various objects, including:
    a. Scene Object: Serves as the root of the scenegraph, defining properties like background color and fog. It establishes the scene's environment.
    b. Mesh Objects: Represent the rendering of specific geometries using specific materials. Multiple mesh objects can utilize the same material and geometry.
    c. Light Objects: Diverse types of lights are utilized to illuminate the scene realistically.
    d. Group and Object3D: Objects used to group other objects, forming hierarchical parent-child relationships. They define the spatial arrangement and orientation of objects.
3. Geometry Objects: Represent the vertex data of distinct geometrical shapes such as spheres, cubes, and more complex objects like animals, buildings, etc.
4. Material Objects: Define surface properties for rendering geometry. This includes aspects like color, reflectivity, and transparency.
5. Texture Objects: Represent images, either loaded from files or generated through canvas or other scenes. Textures are used to enhance the visual appearance of objects.
6. Camera Objects: Define the view of the scene and determine how the scene's contents are projected onto the screen.

Another significant API is WebXR, which has revolutionized the development of immersive experiences that cater to a diverse array of devices, thereby expanding the reach of AR and VR to a broader audience. This API empowers developers to create immersive XR (Extended Reality) encounters within web environments by offering a unified interface for interacting directly with various XR devices like VR headsets and AR equipment through web browsers. It simplifies the process of building web-based applications that adapt to different XR devices and input methods, ensuring a consistent and user-friendly XR experience ("WebXR Device API," 2023).

WebXR streamlines XR application development by providing access to pivotal functionalities, including tracking XR device positions, capturing input from XR controllers, and rendering XR content optimized for distinct devices. By harnessing the power of web technologies such as WebGL for 3D graphics and various Web APIs for user interaction, developers can offer immersive XR experiences without necessitating dedicated apps or complex installations. Notably, this API significantly enhances the accessibility of XR content by allowing users to directly engage with XR experiences via web browsers, eliminating the need for separate app installations. This versatility can be appreciated in Figure 16 ("WebXR Device API," 2023).
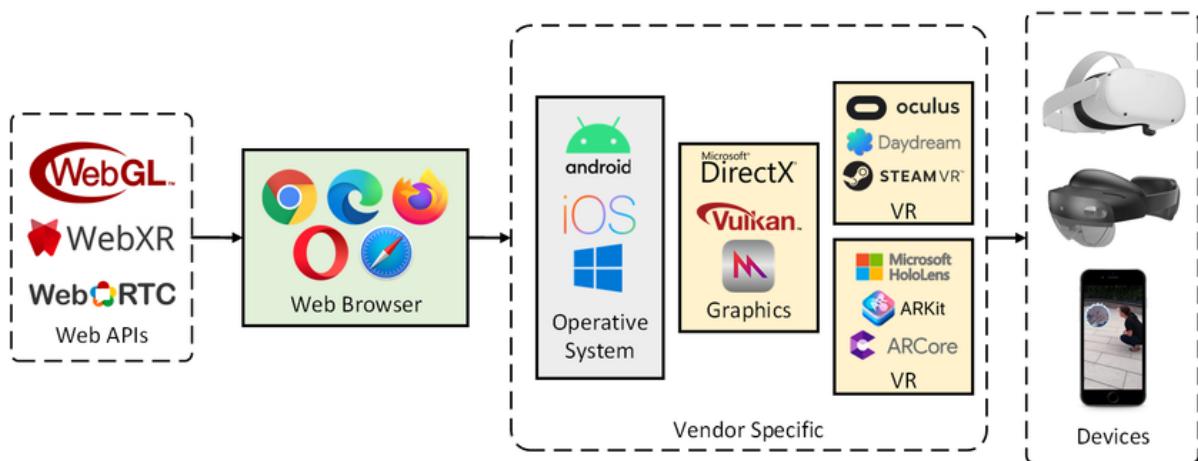
Figure 16 - Web ecosystem for the development of cross-platform AR applications; web APIs get translated into vendor-specific APIs by the web browser (Ferrão et al., 2023)

Most researches that focus on creating virtual environments often employ game engine software like Unity3D or Unreal Engine, which are efficient tools for application development. However, these engines face notable limitations when dealing with the BIM format. Typically, they require the use of plugins to establish a connection with BIM software, which can impede operability by transforming the file format from IFC into a 3D format like FBX or OBJ, resulting in data loss, including properties and even objects (Bao et al., 2022). This conversion process is depicted in the following Figure 17.

One final Software to mention in this section is Blender. Blender is a popular 3D modeling and rendering software, specialized in working with BIM data, that can convert IFC files into GLTF format while preserving the 3D model's geometry and textures. BlenderBIM is a free, open-source, native IFC add-on for Blender, that can be used to analyze, create and modify OpenBIM with Blender ("BlenderBIM Add-on," n.d.).
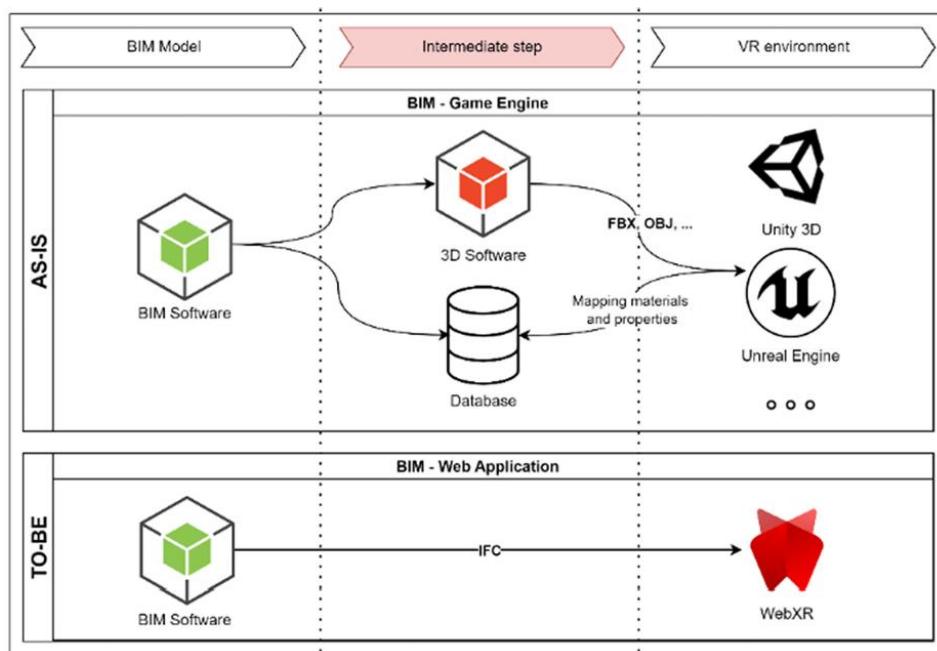
Figure 17 – Comparison between game engine and web application in developing VR content from BIM (Bao et al., 2022)

3. WEB-BASED AR APPLICATION FOR BIMFM

3.1. ASSUMPTIONS, PRINCIPLES, AND PERFORMANCE REQUIREMENTS

The intended purpose of this application is to utilize WebXR alongside with IFC to create an AR environment in a web-based application, making it accessible from a mobile device to align it with a real-world facility. Once the AR environment is created, the user should be able to interact with the virtual assets, obtaining relevant metadata, as desired by the facility manager and the developer. This approach gives complete freedom to the developer, allowing him to fine-tune any desired properties through simple changes in the code, promoting cultural independence and progression in the BIM community. Usual third-party alternatives like Dalux, Unity3D, and Unreal Engine have the main issue of not being open-source options. This type of options tend to be available through subscription payments and sometimes do not even utilize the IFC file format, key element for BIM interoperability and preventing information loss.

Once the AR environment is engaged, users can explore the virtual space, navigate through the BIM model, and interact with various displayed objects. Upon tapping any object within the AR environment, the application provides pertinent facility management properties. This BIM information to be displayed, is meant to empower facility managers to make informed decisions, enhance productivity and collaboration, and reduce errors. The application operates under the assumption that a comprehensive BIM model serves as the primary data source, encapsulating pertinent building information stored in the IFC file format, such as geometrical and non-geometrical information.

The project's scope centers on the development and testing of the AR-based application, which differs from its future real-world production scenario. The latter would encompass tasks like database interactions and API communication. The testing process employs the developer's computer equipped with a local development server, a local network, and an Android mobile phone compatible with the ARCore API and with the Google Play Services for AR application installed and activated.

IFC files are read from the "assets" folder, stored in the web server. Before launching the application, the BIM model in IFC file format must be uploaded to ensure its availability. Figure 18 describes the complete data flow in this system.
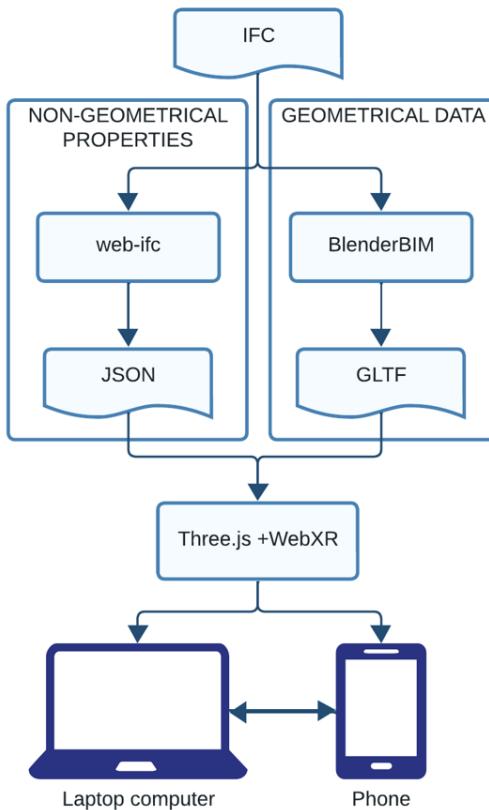
Figure 18 – Data Flow Diagram from IFC Model to AR Environment

The data flow starts with the IFC file as input data. The first step in the process is to convert the IFC files into GLTF (GL Transmission Format) files. GLTF is a widely used 3D file format optimized for efficient transmission and loading in web applications. BlenderBIM is used in the backoffice of the system for this conversion thought an automated script. BlenderBIM is an open-source add-on for Blender. Blender being a popular 3D modeling and rendering software that is able to convert IFC files into GLTF format while preserving the 3D model's geometry and textures. Once the IFC files are converted into GLTF, they are ready for AR visualization, so are loaded into the application using the GLTFLoader provided by three.js to view 3D models in real-world environments.

To access BIM properties and metadata associated with the 3D models displayed in AR, the system utilizes the web-ifc library. This library allows developers to extract and work with BIM data contained within IFC files using JavaScript through JSON format, which is a lightweight data-interchange format. Users then can interact with the AR visualization, and when they select or interact with specific elements of the 3D model, the associated BIM properties are retrieved from the web-ifc parsed data and displayed in real-time within the AR interface. This interaction can involve tapping on objects in the AR view to access their metadata, querying BIM properties, or even triggering actions based on the data, such as maintenance instructions or construction plan.

The application's interface ensures appropriate dimensions and transparency, enabling manipulation and interaction with the BIM model. In the development and testing phase, the AR application is run through a local development server provided by tools like Webpack. This local server acts as the backend. When the app runs, the server compiles the JavaScript code, manages assets such as images, models, and fonts, and serves them to the frontend.

The frontend, which includes the HTML canvas element for rendering AR content, communicates with the local server to obtain the necessary resources. This setup allows the developer to test and refine the application's functionality, interactions, and rendering on different devices. The local server simulates the backend behavior, such as handling interactions, rendering 3D models, and responding to user input. This approach is crucial for development, as it provides a controlled environment to identify and resolve issues before deploying the app to a production scenario. The following Figure 19 shows a representation of the frontend's functioning for the Web-based AR application created and its respective outputs.
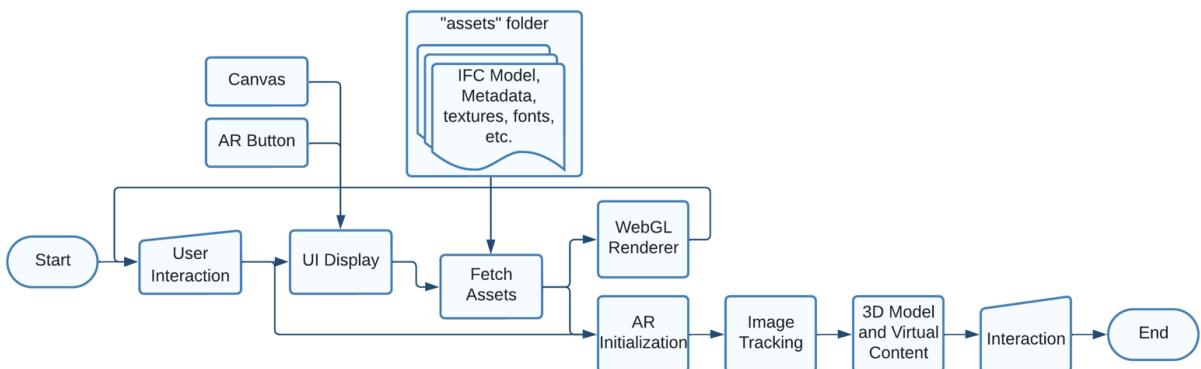
Figure 19 – Application's Frontend Workflow Diagram

The application's process to create the immersive AR experience starts when users access it through web browsers. This interaction initiates the appearance of a user interface (UI), featuring an HTML canvas. An AR activation button enables the application to engage AR mode using WebXR technology. The application uses the "assets" repository to retrieve any necessary static resources like 3D models, textures, or images. These resources serve as the fundamental building blocks for constructing the AR environment. The device's camera and sensors allow the creation of the AR environment, and utilizing image tracking, a technology that detects and establishes real-world images as reference points, it overlays virtual content onto the physical environment. 3D models use libraries like Three.js to populate the AR scene, infusing depth and realism. User interactions subsequently animate the AR experience, allowing users to navigate, manipulate, and interact with virtual elements.

The development of the application is facilitated using the Visual Studio Code software, this choice was made based on its reputation as a lightweight yet robust code editor. Its popularity is attributed to its comprehensive suite of features, encompassing coding, debugging, and project management functionalities. Its versatility in accommodating different programming languages made it an apt choice for AR application development.

3.2. PLATFORM CREATION AND FUNCTIONALITY

The AR-based application was elaborated using a local development server on VS Code on one computer and a browser on an Android mobile phone for constant testing. The following functionalities were set to outline the reach of the use of AR in a BIMFM environment.

1) BIM Model Upload: The BIM Model Upload through IFC allows the application to integrate with BIM to extract relevant data such as geometry, properties, and relationships. Figure 20 shows how this data is used to create a virtual representation of the building in the web browser.
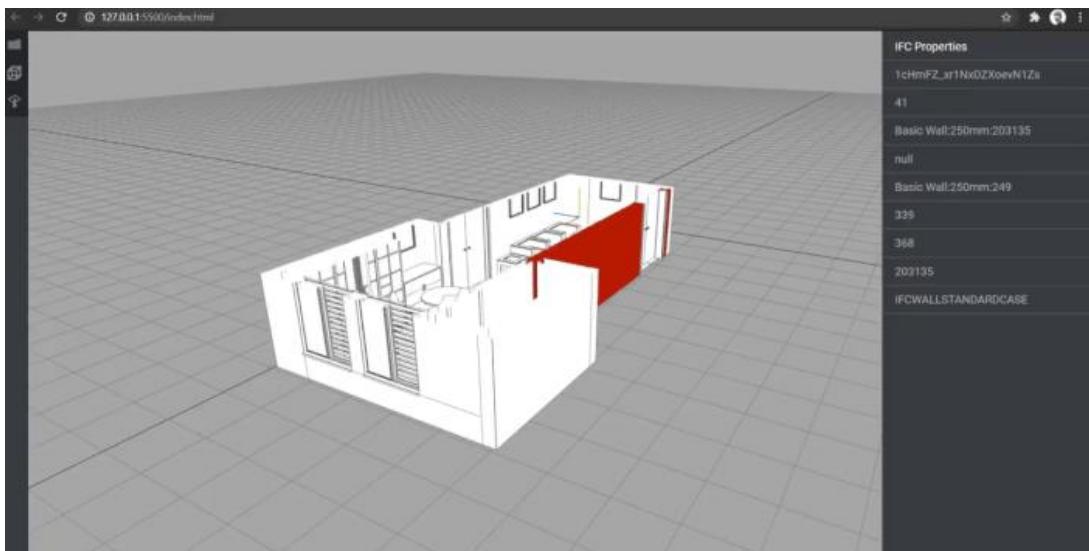
Figure 20 – Functionality #1: BIM Model Upload ("IFC.js," n.d.)

2) AR Visualization: Figure 21 exemplifies how the AR Visualization provides the user with a seamless AR experience that overlays virtual elements onto the physical environment.
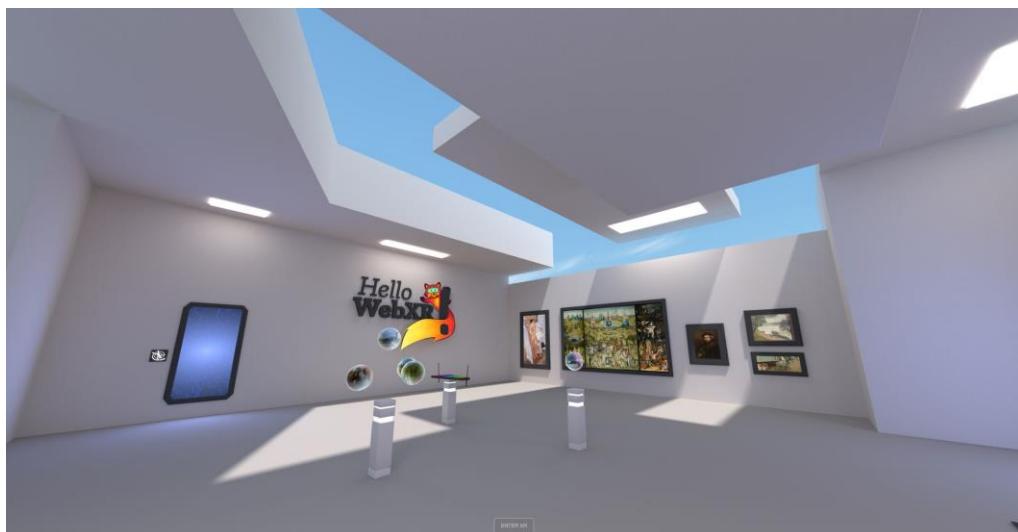
Figure 21 – Functionality #2: AR Visualization and Immersion Experience ("WebXR Device API," 2023)

3) Image Tracking: Figure 22 shows the use of Image Tracking to detect and track specific images in the real world as markers for anchoring virtual content to physical locations.
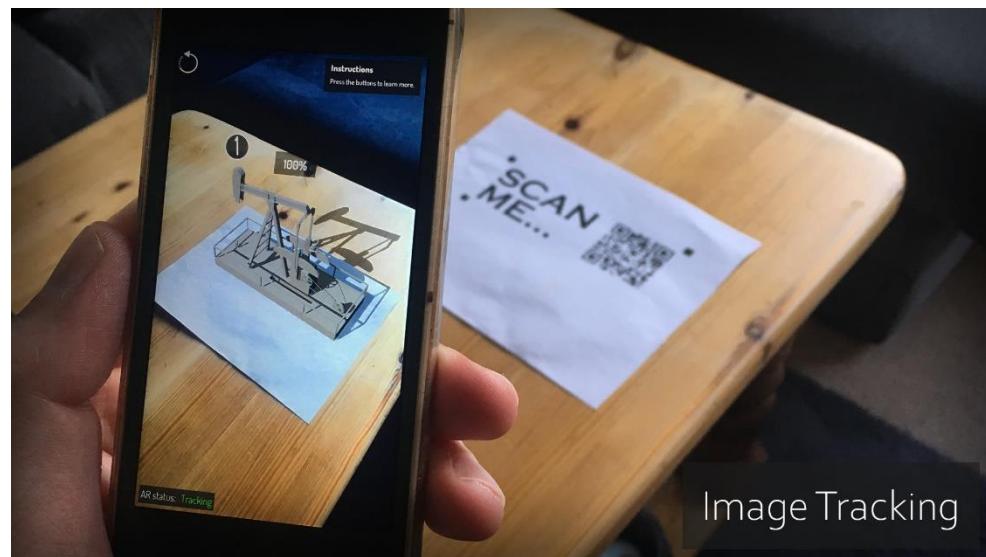
Figure 22 – Functionality #3: Image Tracking ("Unreal Engine," n.d.)

4) Immersion Experience: AR Visualization and Image Tracking combined allow for an Immersive Experience, where users can manipulate, navigate, and engage with the virtual content, enhancing their exploration and understanding of the facility. The application ensures a responsive experience by recalibrating the rendering of virtual content based on user interactions, this real-time feedback creates a fluid and engaging AR experience.

5) Dynamic Data Access: This functionality provides real-time access to metadata stored within BIM models, as shown in Figure 23. Users can interact with objects in the AR environment to retrieve detailed information about them, enhancing decision-making processes. By combining BIM data, AR technology, and user interactions, the application creates an immersive experience that enhances facility management operations, decision-making, and engagement.
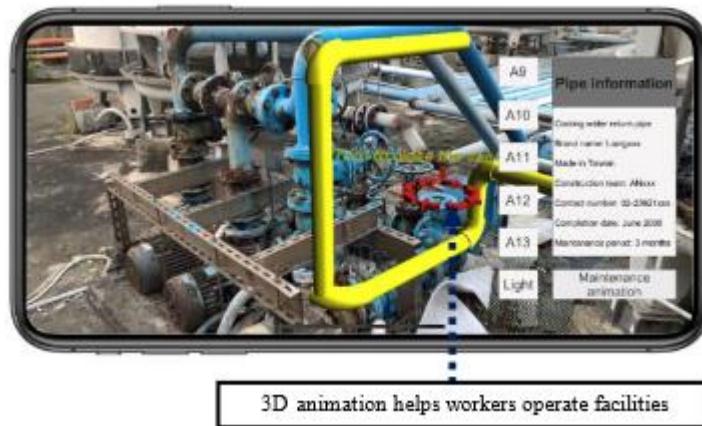
Figure 23 – Functionality #4: Dynamic Data Access (Diao and Shih, 2019)

The following Figure 24, shows the workflow of the development and testing process for the Web-Based AR Application for BIMFM.
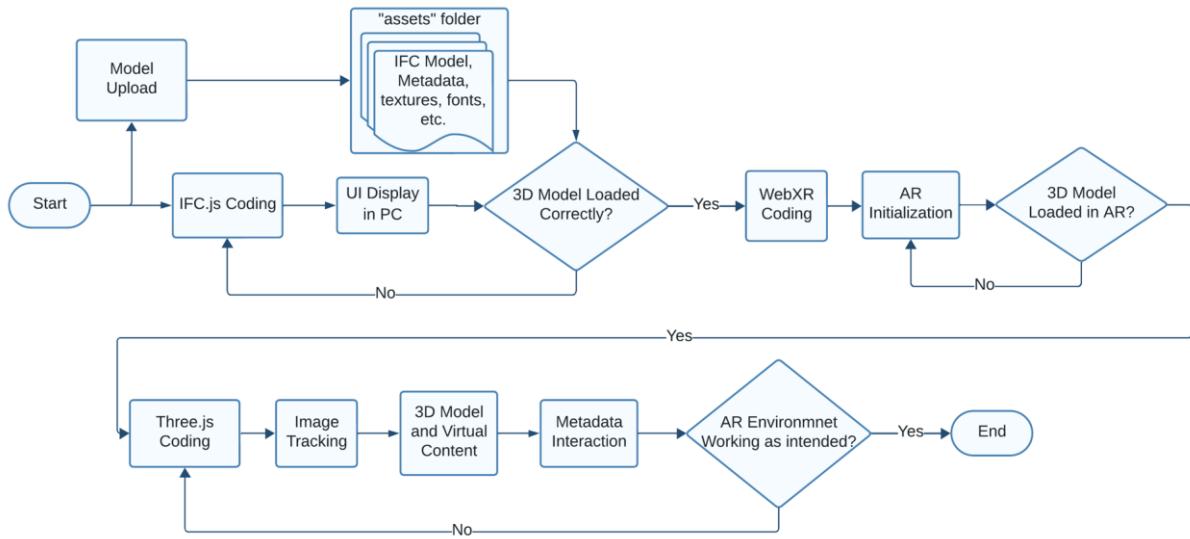
Figure 24 – Application's Frontend Development and Testing Workflow

This workflow centers around a strong trial and error programming process, utilizing multiple libraries and APIs to set the 3D Model, the AR environment, and any other functionalities to be added to further the BIMFM experience, like image tracking, metadata interaction, etc. These specific processes will be explained in detail in the following sub-section.

3.3. APPLIED LIBRARIES AND APIS

The setup of the AR development environment revolved around utilizing VS Code (Visual Studio Code) as the primary tool. To build up the interface, programming languages HTML, CSS, and JavaScript were used. Multiple main elements were imported from the Three.js library, like Cameras, Mesh, Lighting, Controls, Raycaster, Materials, etc. The WebGL and WebXR APIs were imported from the Three.js library and used to create the three-dimensional objects and the AR environment, respectively. The IFC.js library was used to import the IFC loader used, all other model loaders were imported from Three.js.

Three.js

Multiple objects like Scene, Camera, Lighting, Controls, and Raycaster were imported from the Three.js library, serving as main objects to configure the scene and the AR environment, as well as to add functionality options to it. Following Figure 25 shows the creation and specifications of some of this main objects.

```
// Scene where the render objects are placed
this.scene = new Scene();

// Camera to define the perspective used to view the scene
this.camera = new PerspectiveCamera(60, 1, 0.1, 1e4);
this.camera.position.set(0, 10, 0);
this.scene.add(this.camera);

// Ambient light
this.scene.add(new AmbientLight(0x777777));
// Point light used to iluminate the scene for a point in all directions
this.point = new PointLight();
this.scene.add(this.point);

// Orbit controls are used for interaction in non-AR environment
this.controls = new OrbitControls(this.camera, this.canvas);
this.controls.listenToKeyEvents(window);
```

Figure 25 – Code used to create the Scene, Camera, Lighting, and Controls

The "scene" acts as a canvas onto which various visual components are placed and arranged. Within this container, 3D models, lights, cameras, and other graphical elements are positioned and interact with each other. The scene handles the placement and positioning of objects in a 3D coordinate space, facilitating the creation of a coherent and immersive AR environment.

The "camera" employed enables users to perceive the 3D environment by capturing and projecting the scene onto a 2D screen, replicating the experience of looking at objects in a real-world space. This "camera" is created using the PerspectiveCamera class from the three library. This type of camera simulates the behavior of a real-world camera with perspective projection. It takes into account the position, orientation, and field of view to determine how objects in the scene appear to the viewer.

Two types of light sources are employed: "AmbientLight" is a type of light source that provides uniform illumination throughout the scene, simulating the effect of indirect light bouncing off surfaces. It does not have a specific direction or position but rather evenly brightens all objects in the scene. This light helps eliminate harsh shadows and ensures that objects are visible even in areas where direct light does not reach. "PointLight" is another type of light source that simulates an omnidirectional light originating from a single point in space. It radiates light outward in all directions, creating realistic shadows and highlights on objects. This type of light is useful for simulating light sources like bulbs or candles. It has properties such as intensity, color, and distance attenuation, which determine how the light interacts with objects based on their proximity. The combination of ambient light and point light creates a sense of realism, allowing users to perceive the depth, shape, and material properties of objects more accurately.

The controls utilized in the application play a crucial role in enabling users to interact with the 3D scene effectively. The "OrbitControls" class is employed to provide a user-friendly way to manipulate the camera's position and orientation, enhancing the user's ability to explore and navigate the virtual environment. It simplifies the process of managing user input and translating it into smooth camera movements.

```
// Update raycaster using the positions of the mouse
const pointer = new Vector2(); //2D vector to keep track of the mouse
pointer.x = (this.mouse.position.x / window.innerWidth) * 2 - 1;
pointer.y = (-this.mouse.position.y / window.innerHeight) * 2 + 1;

// Setting the raycaster from camera to pointer to obtain the interesting objects
const raycaster = new Raycaster();
raycaster.setFromCamera(pointer, this.camera);;

// If there are intersections, handle them
if (this.mouse.buttonJustPressed(MouseButton.LEFT)) {
    // Perform intersection checks with objects in the scene
    const intersects = raycaster.intersectObjects(this.scene.children);
    if (intersects.length > 0) {
        const obj = intersects[0].object;
```

Figure 26 - Raycaster code used for the Application

The raycasting mechanism revolves around projecting an imaginary line from the user's interaction point—usually defined by the mouse cursor—onto the various objects present in the augmented reality scene. This process involves translating the mouse's screen coordinates into normalized device coordinates. Achieved through the use of a dedicated 'Vector2' object named 'pointer,' this ensures consistent interactions, independent of the screen's resolution.

At the core of the raycasting process lies the creation of a 'Raycaster' instance known as 'raycaster.' Configured through the 'setFromCamera' method, this object brings together two pivotal elements: the normalized interaction coordinates held within the 'pointer' vector, and the virtual camera linked to the scene. This union establishes both the ray's origin point, representing the camera's position, and its trajectory—from the camera through the mouse pointer. Following the raycaster's configuration, it starts checking intersections with the objects inhabiting the scene. The results of these checks is encapsulated within an array labeled 'intersects.' This array serves as a repository for pertinent intersection information.

WebXR – AR Environment, Image Tracking, and Interaction

WebXR is integrated into the application to create immerse and interactive with AR in web browsers. In this specific code, WebXR is used to set up the AR environment, enable image tracking, and handle user interactions.

```
// Renderer is used to draw the scene into the screen
this.renderer = new WebGLRenderer({canvas: canvas, antialias: true});
this.renderer.xr.enabled = true;
```

Figure 27 – WebXR Initialization in Code

Figure 27 shows how WebXR is initialized when the application is loaded. 'WeBLRenderer' is configured to enable XR technologies, allowing the application to render 3D graphics in the AR environment.

```
// Enable XR button and load marker data set 'image-tracking' as optional feature
const arButton = ARButton.createButton( this.renderer, {
    optionalFeatures: [ 'image-tracking' ],
    trackedImages: [
        {
            // Load market to be tracked
            image: await this.loadImage('assets/marker.jpg'),
            widthInMeters: 0.2
        }
    ]
} );
document.body.appendChild(arButton);
```

Figure 28 – WebXR use to create "Start AR" button

In the application's code snippet shown in Figure 28, it specifies the optional feature of image tracking, allowing it to interact with the device's camera and sensors. It also shows the AR activation button creation, which will be labeled tith "START AR", allowing the application to initiate the AR mode.

For the image tracking setup, WebXR allows the application to detect and track a specific image in the real world, using an image in the assets folder as a base on what to look for ('assets/marker.jpg'), this QR image used for testing purposes is shown in Figure 29,
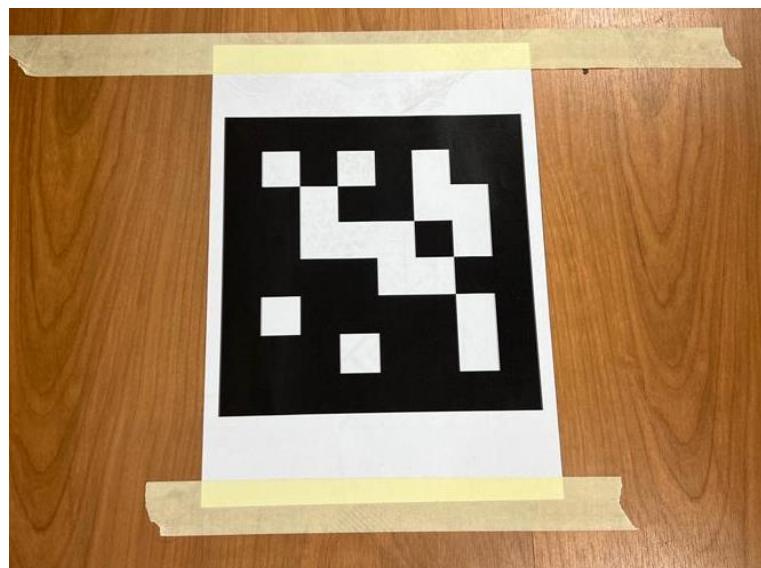
Figure 29 – QR image used for Image Tracking

The following Figure 30 exemplifies this feature by placing a real-life marker on a table and placing a complete model with reduced dimensions on it with AR. This exact technology can and will be used to place and tune any model into the exact location of their respective facilities.

Figure 30 – Image Tracking Use to place a model on a table

WebXR is an API that's able to integrate with the WebGL renderer, so the application is able to render all the 3D graphics into the AR environment seamlessly. WebXR facilitates the ability to change the position and orientation of any object, which is vital when placing virtual content in the AR scene.

IFC.js

The IFC API is a component of the "web-ifc" library, which specializes in handling IFC files. This loader enables the application to import IFC files into the application in order to get metadata associated with the objects in the scene.

```
const IfcAPI = new IfcAPI ();

IfcAPI.Init();

// Load IFC file from text content
async function loadFile(ifcAsText) {
    const uint8array = new TextEncoder().encode(ifcAsText);
    const modelID = await OpenIfc(uint8array);
    const allItems = GetAllItems(modelID);
    const result = JSON.stringify(allItems, undefined, 2);
}

// Open IFC file with metadata
async function openIfc(ifcAsText) {
    await IfcAPI.Init();
    return IfcAPI.OpenModel(ifcAsText);
}

// Get all data available in the IFC file
function getAllItems(modelID, excludeGeometry = false) {
    const allItems = {};
    const lines = IfcAPI.GetAllLines(modelID);
    getAllItemsFromLines(modelID, lines, allItems, excludeGeometry);
    return allItems;
}
```

Figure 31 – IFC Loader used for the Application

Figure 31 illustrates a code segment that demonstrates the practical application of the IFCApi within the context of this software. "web-ifc" could also be used for visualization purposes, instead of converting files to GLTF, the IFCLoader parses the structured data from the IFC files into 3D mesh objects to render within a Three.js-based application.

During this specific research, an issue arose where the loaded objects weren't processed correctly into individual mesh objects for Three.js handling. Given this issue, the proposed solution was to perform an internal conversion from the IFC file into a GLTF file, which would maintain only the geometrical data, but could create separate mesh successfully for every individual object loaded. The IFCLoader presents a limitation where it is not able to provide individual Three.js objects that could be later correlated with the metadata available in the IFC file, instead it creates a single mesh for visualization purpose only.

To overcome this limitation of the IFCLoader the data is converted into GLTF that will keep the identification of each individual object available so that is can be later correlated with metadata read from the IFC file.

3.4. BACKEND AND FRONTEND COMPONENTS

The following Figure 32 shows a diagram including main components of backend and frontend of the Web-based AR application developed.
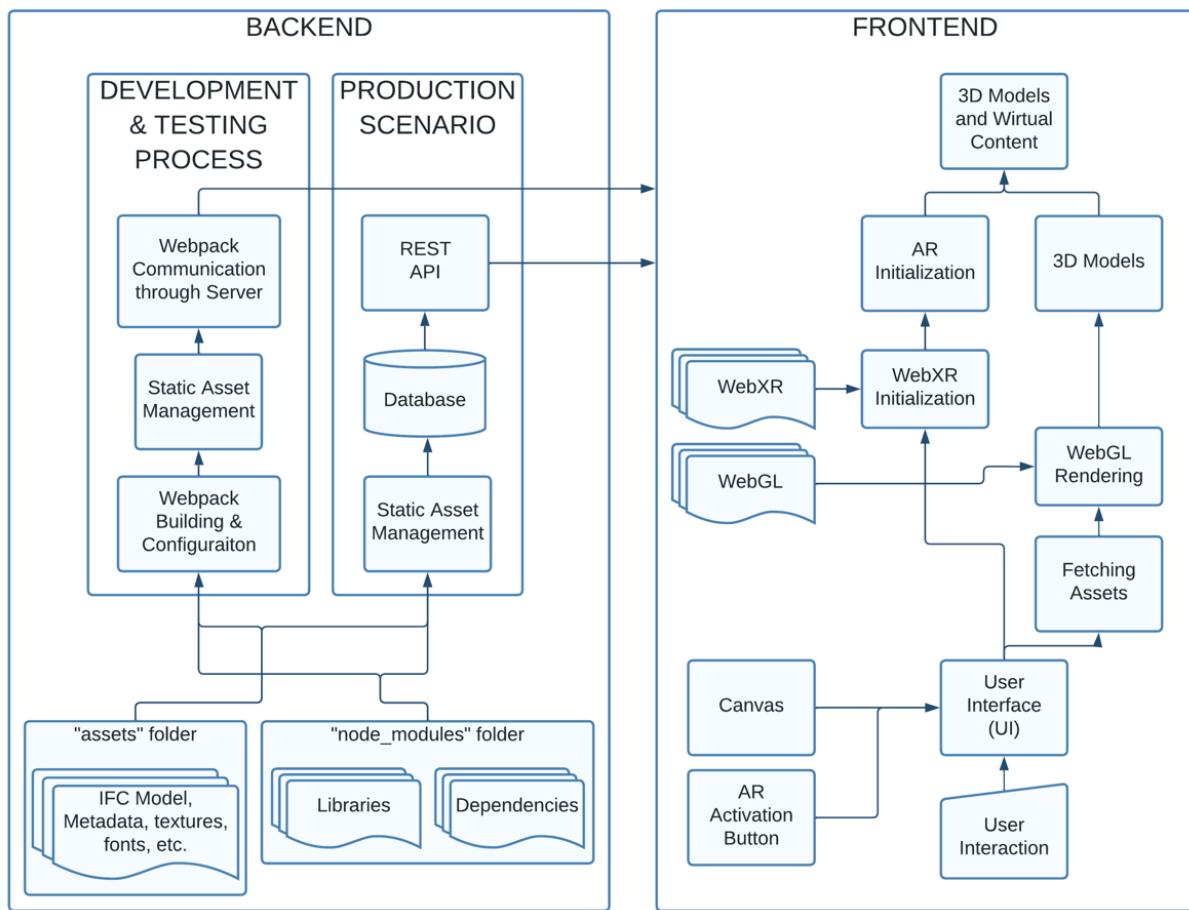
Figure 32 – Backend and Frontend Components

The development and testing of the AR-based application involve distinct setups for these two phases when compared to a real-world production scenario. As depicted in Figure 32, the backend component showcases this difference, while all other aspects outside these scenarios remain the same. During the development and testing phase, the AR application is executed via a local development server facilitated by Webpack's 'webpack-dev-server'. This server effectively serves as the backend during testing, handling tasks like JS code compilation and asset management, such as images, models, and fonts, which are then delivered to the frontend.

The process initiates with the "Asset Folder," acting as a repository for essential resources such as IFC files, metadata, and static assets. "Static Asset Management" ensures the distribution of these assets from the Asset Folder to a designated build directory. This allocation guarantees their accessibility during frontend runtime. The local development server binds to an IP address and port number within the local network, fostering communication between the developer's computer and mobile device. This dynamic connection empowers real-time updates, automatically detecting changes on the mobile device without necessitating manual page reloading.

In a more complex real-world production scenario, the AR application is designed for actual user access. The backend infrastructure comprises database housing assets such as images, models, and fonts. The backend also exposes a REST API, enabling the frontend to request data or actions like retrieving specific 3D models or acquiring information about building elements. The backend processes these

requests, interacts with the database, and furnishes the required data in a format comprehensible to the frontend.

The frontend workflow commences with user interaction, as individuals access the application via web browsers. The "User Interface (UI)" provides an intuitive platform, housing primary components like the AR activation button and the HTML canvas. "Fetching Assets" procures static resources including 3D model files and textures from the Asset Folder. "WebXR Initialization" constitutes a pivotal preparatory step, utilizing WebXR capabilities to enable interaction with the device's camera and sensors, bridging the virtual and real realms. "WebGL Rendering" further advances this process, harnessing processed data to craft captivating visual elements. By leveraging WebGL technology, it transforms database data into an immersive AR experience, playing a pivotal role in constructing the visual facets of the AR scene.

The spotlight then turns to "3D Models," which are incorporated using Three.js to infuse virtual content with life. These models seamlessly merge with the real world, crafting an immersive experience. Converging the frontend tasks, the "3D Models and Virtual Content" phase achieves the integration of virtual elements and reality, merging processed data with advanced rendering techniques. This interplay between backend and frontend ensures an effective transformation of raw data into an immersive AR encounter, blurring the boundaries between the virtual and real realms.

3.5. USER INTERACTIONS

For the best possible user experience, it is advisable to access this application through a mobile web browser due to the ease and AR compatibility of mobile devices. Upon accessing the application, users are presented with a prominent HTML canvas element that exhibits a 3D render of the active model. A clearly labeled "START AR" button encourages users to commence their augmented reality experience, as illustrated in Figure 33.
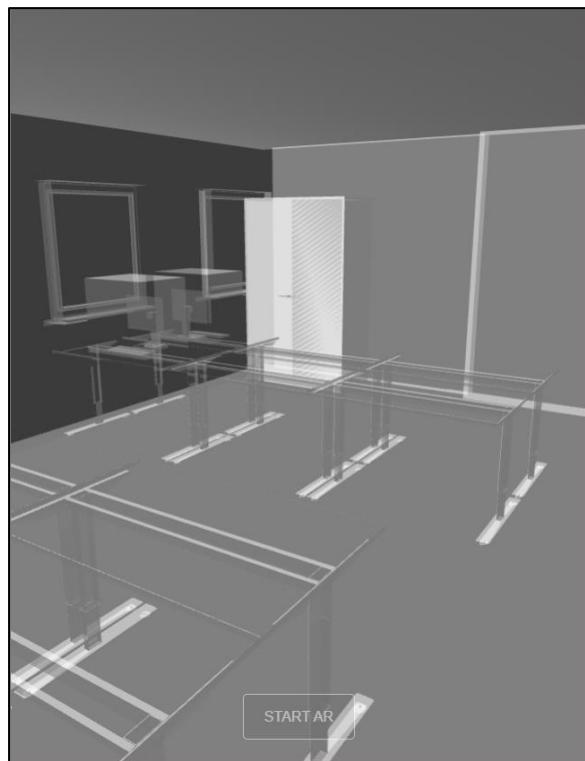
Figure 33 – Initial View of the AR Application, before AR activation

Upon activating AR mode, the canvas transforms into a window that shows the AR scene, granting users the ability to explore the AR environment from diverse viewpoints. Designed with user-friendliness at its core, the control scheme delivers a seamless and intuitive interaction experience. By facilitating unrestricted movement and instinctive touchscreen engagement, these controls establish an efficient connection between the user's intentions and the responsiveness of the AR environment, as shown in the following Figure 34. The application serves as a real-time conduit of feedback for users, providing dynamic updates that mirror their actions. As users interact with the environment, the application responds promptly, adjusting the rendering to match their directives.

Figure 34 – AR Environment View of the Application

A central facet of this experience is the real-time access and presentation of metadata extracted from IFC files. The IFC Loader (web-ifc) serves as an intermediary, by translating the IFC metadata into information readable by Three.js, assigning them to the respective objects in the 3D model.

The concept of ray casting gives users the ability to interact with objects directly through their mobile screen and pick any object to obtain their metadata information. Once the object is selected, a text mesh is created to display any information desired about that object. The following figures show how more properties can be retrieved and shown through simple coding as desired by the facility manager. Figure 35 displays how it is only necessary to define a new Mesh, Text object, and its position to show both properties, in this case these were Name and Manufacturer, as shown in Figure 36.

```javascript
// We just want the first interesting objects, not all of them
if (intersects.length > 0) {
    const obj = intersects[0].object;
    console.log('Object Properties:', obj);
    //Define all requested text objects
    const nameText = 'Name: ' + obj.Name;
    const manufText = 'Manufacturer: ' + obj.Manufacturer;

    // Display all the requested object in text and destroy after 2 secs
    this.createText(
        nameText,
        manufText,
        new Vector3(obj.position.x-100, obj.position.y+180, obj.position.z),
        new Vector3(obj.position.x-100, obj.position.y+150, obj.position.z),
        (nameMesh, manufMesh) => {
        setTimeout(() => {
            nameMesh.removeFromParent();
            manufMesh.removeFromParent();
        }, 2000);
    });
```

Figure 35 – Test of code used for Dynamic Data
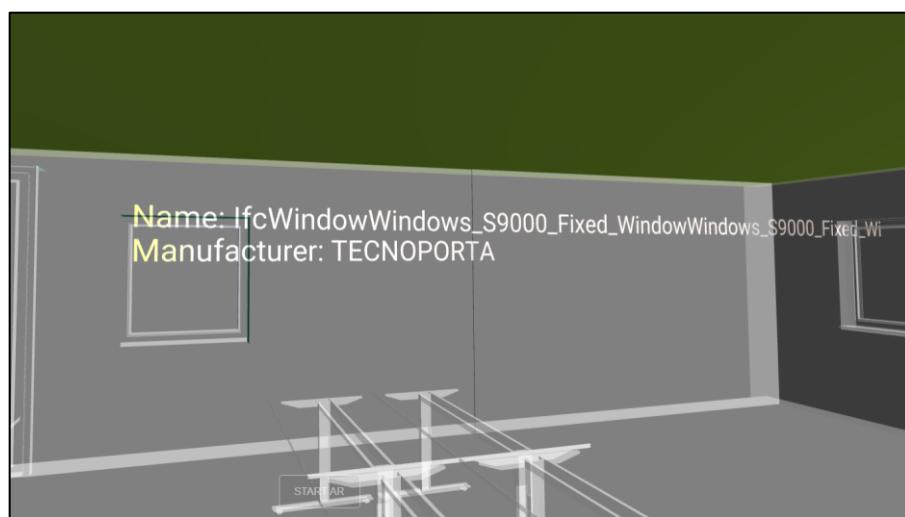
Figure 36 – Test Results for Dynamic Data

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4. CASE STUDY DEMONSTRATION

4.1. GENERAL DESCRIPTION

The case study centers on the implementation of the Web-Based AR Application for BIMFM within the facilities of EQS Global. To manage the AR environment testing process, it was decided to confine the scope to a single 100 m2 room. In Figure 37 below, the actual interior of this chosen room can be observed, which serves as an office space featuring a diverse array of objects.
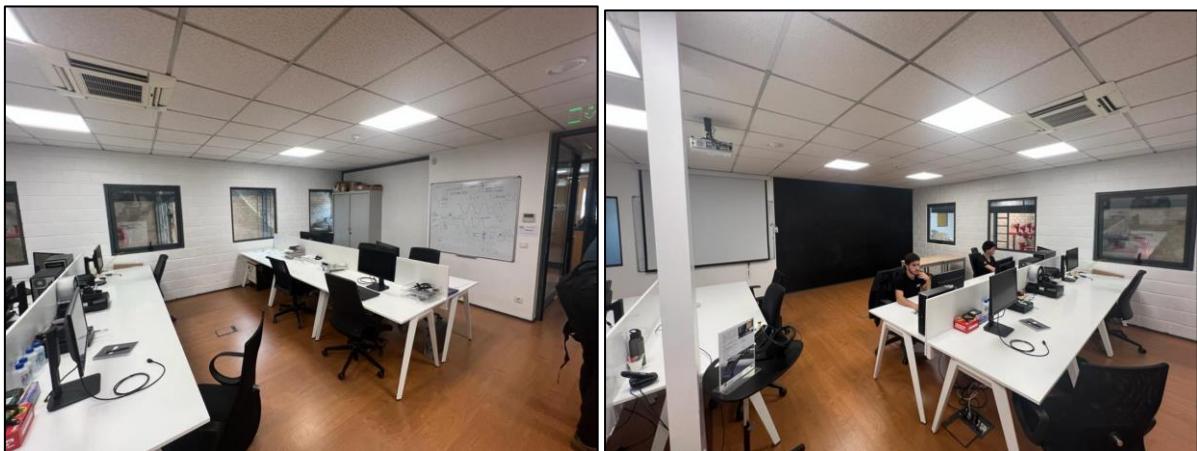
Figure 37 – Inside View of Selected Facilities for Case Study

The authoring platform selected for creating the BIM model is Revit 2023 by Autodesk. This choice is based on several factors, including the accessibility of the latest versions, the presence of all desired functionalities, and alignment with the project's specific requirements. The process began by creating a BIM model in Revit, alongside the acquisition of a precise point cloud through laser scanning. In the alignment phase of the model and point cloud, always aiming to maintain an approximate accuracy level of 1 cm. Subsequently, the model was exported into the open-format IFC file format. This model specifically includes critical elements such as walls, ceilings, floors, columns, doors, windows, as well as essential assets like desks, computers, and storage units. All other items like chairs, whiteboards, and general decorations were left out of the scope of the model for redundancy reasons, considering the main goal of the thesis is to test the developed application. To ensure its relevance, the selection of properties was guided by ISO 55000, ISO 55001, and ISO 55002 standards, enriched by valuable discussions with the EQS Global team. This collaborative effort ensured the identification of only the pertinent properties essential for effective facility management across the infrastructure's entire lifecycle.

The current chapter provides a comprehensive overview of the case study, survey methodology, data capture process, level of information need, BIM model creation, IFC export setup, and the evaluation of the application within the case study context. The case study revolves around the implementation of a Web-Based AR Application for BIMFM within EQS Global's facilities. This involves utilizing Revit 2023 for BIM modeling and laser scanning for data acquisition. The determination of the level of information need is carried out in accordance with industry standards, leading to the creation of a comprehensive BIM model that is meticulously aligned with the point cloud data. This model is then

exported in the IFC format, and the chapter concludes with an evaluation of the application's performance, showcasing successful testing of AR integration and dynamic data access.

4.2. SURVEY METHODOLOGY AND DATA CAPTURE

To create an immersive AR experience, an essential step involves conducting a digital-driven survey to ensure the BIM modeling closely mirrors reality. For this purpose, a laser scanning approach was selected by the EQS Global team, employing the FARO S70 Focus Laser Scanner that was available in the office. This scanner provides exceptional accuracy, as defined in its tech sheet with a ranging error, measured around 10m and 25m, of ±1 mm. This means its LOA (Level of Accuracy) ranges between LOA40 and LOA50, following USIBD Level Of Accuracy (LOA) Specification Guide, proving a very high-quality data for the project. The audit was conducted by a qualified specialist from EQS Global, lasting approximately one hour, involving the assessment of seven survey control points, as depicted in Figure 38. The amount and location of the survey control points was decided by the respective specialist, with the intended goal to cover most of the office area.
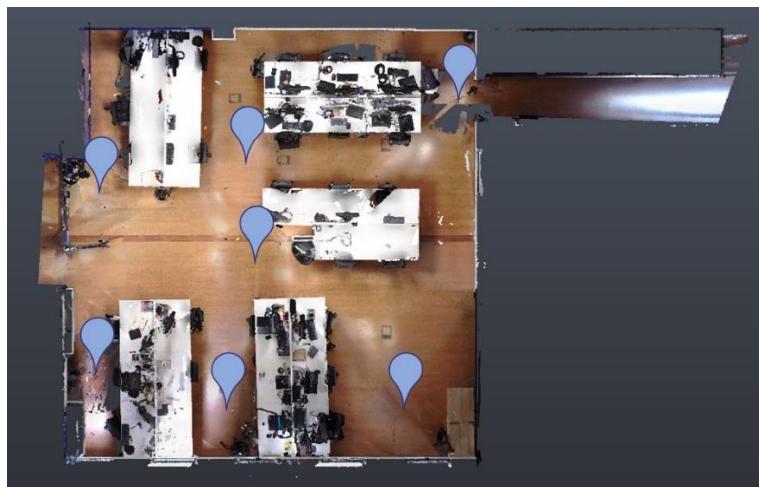
Figure 38 – Survey Points used in Laser Scan procedure

These seven survey control points produced an Autodesk Recap scan file in .rcs format, which serving as the primary data source for aligning the Revit model with the actual facilities, as shown in Figure 39. Subsequently, this file was incorporated into the Revit document as a Point Cloud, and local references were used for precise alignment. This alignment process involved anchoring the scan data to a specific reference point and locally aligning the four corners with the pre-existing model.
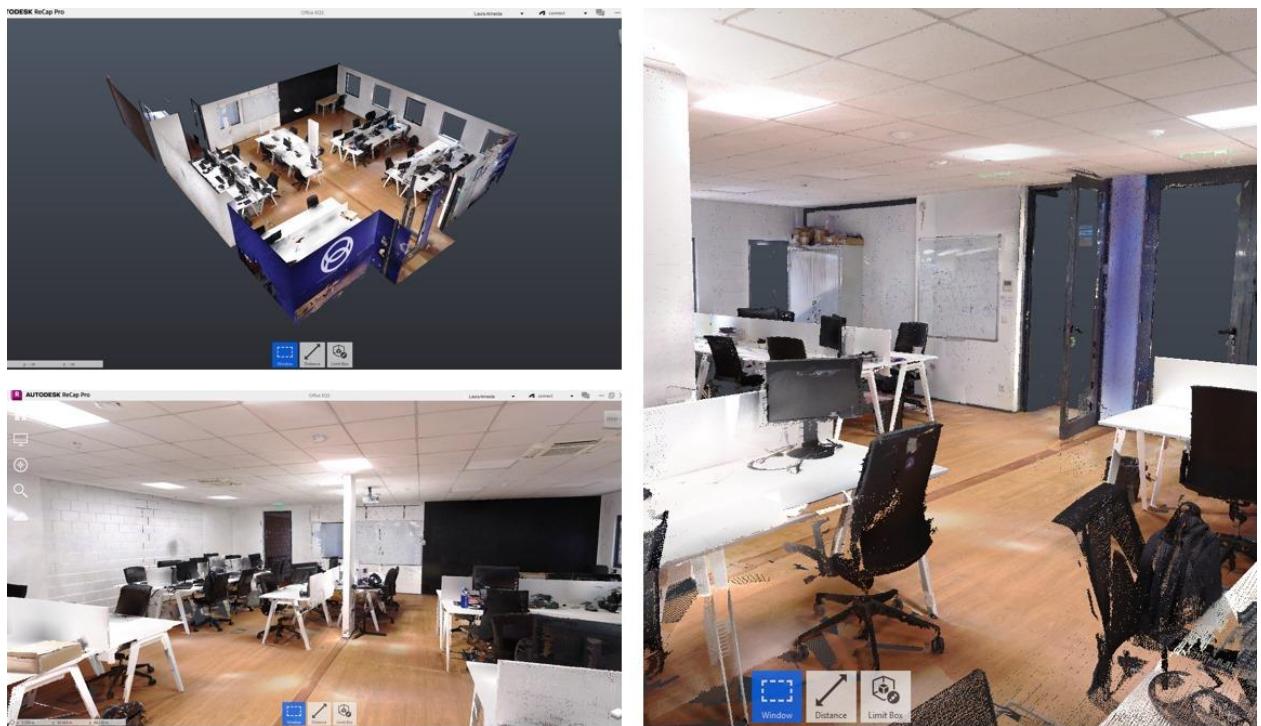
Figure 39 – Point Cloud file as seen in Autodesk ReCap

Concurrently, a preliminary model was manually generated in Revit 2023, utilizing measurements gathered through conventional handcrafted methods. This initial model (shown in Figure 40) established a baseline for the subsequent alignment process, facilitating the seamless integration of laser scan data with the Revit model.
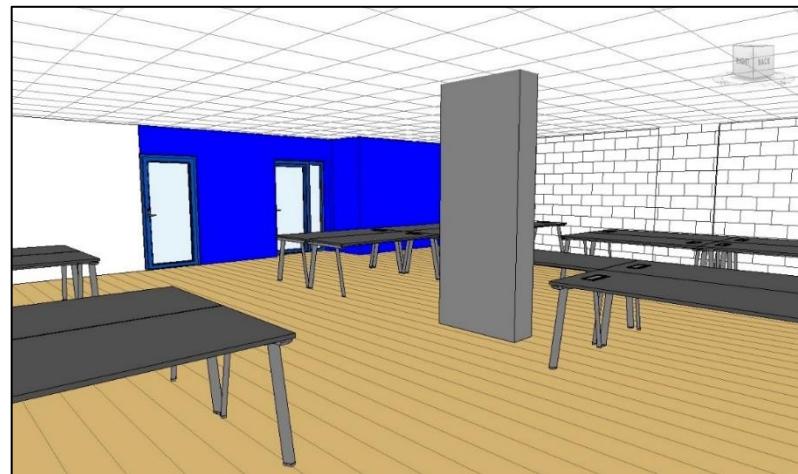
Figure 40 – Initial Revit Model done before alignment process

4.3.   LEVEL OF INFORMATION NEED

The Level of Information Need and its prerequisites are fundamentally grounded in industry standards. BS EN 17412-1:2020 Building Information Modelling offers valuable guidelines for discerning the specific information requirements across various facets of BIM projects.

Termed "Felipe Moreira's BIM A+ Dissertation," this developed framework serves the purpose of streamlining information provisioning, eliminating redundant data, and minimizing waste. To effectively determine the Level of Information Need for each information deliverable, certain prerequisites must be met. The initial prerequisite centers on clearly defining the purpose of the information, while the second revolves around pinpointing crucial project lifecycle milestones where this information becomes indispensable. Lastly, the third prerequisite entails identifying the specific actor responsible for generating or supplying the requisite information. All these prerequisites are concisely outlined in Table 1 for clarity and reference.

Table 1 – Prerequisites for Level of Information Need "Felipe Moreira's BIM A+ Dissertation"

Purpose	The purpose of the model is to test the seamless integration of BIM information, granting users real-time access to critical data through the AR-enhanced tool. By linking objects to external databases through specialized middleware, the model facilitates Facility Management, specifically the subset of Asset Management. This integration enables users to visualize, interact, and explore BIM objects alongside their associated meta-data, to create a user-friendly environment that enhances productivity, reduces errors, and facilitates informed decision-making during facility management operations. According to the BIMe Initiative's Model Uses Table, this use was identified as Asset Maintenance code 6010.
Milestone	The defined milestone for the model is set on a specific date, considering that the facilities are already in use. This date, 01/08/2023, is based on the thesis project's timeline and the required testing process for the AR-enhanced tool. Meeting this deadline is crucial to ensure the project's timely completion and successful implementation.
Actor	As the person in charge of this asset management project, the designated actor responsible for creating and overseeing the model will be Engineer Felipe Moreira, fulfilling the role of Asset Manager. This role corresponds to the area of Asset Manager Roles, Code Ro_10_30_50, as per the UniClass 2015 codes.
Object	The Level of Information Need is specifically linked to certain elements in the model, outlining key properties that are considered crucial by the EQS company for effective asset maintenance. The modeled objects encompass: • Walls - ifcWallStandardCase • Columns - ifcColumn • Floor - ifcSlab • Ceiling - ifcCovering • Doors - ifcDoor • Windows - ifcWindow • Desks - ifcFurnishingElement • Computers and Storage Unit – ifcBuildingElementProxy

Within the framework of "Felipe Moreira's BIM A+ Dissertation," the Level of Information Need is distinctly tailored to target specific elements within the model, encompassing critical components such as walls, columns, floors, ceilings, doors, windows, desks, storage units, and computers. By meticulously defining the Level of Information Need for each of these entities, the AR-enhanced, BIM-assisted tool implemented at EQS Global becomes exceptionally adept at addressing precise information requirements. This refined strategy ensures that the model delivers precisely the right information when needed, thereby creating an ideal testing environment for the AR-enhanced application.

Table 2 – Part #1 of Level of Information Need "Felipe Moreira's BIM A+ Dissertation"

Alphanumerical Information		
Element	**Identification**	**Information Content**
Walls, Columns, Floor and Ceiling	Name, Description	Not requested
Doors, Windows, Desks, Storage Unit, and Computer	Name, Description, TagNumber	Manufacturer, ManufacturerURL, InstallationDate, WarrantyStartDate, WarrantyDescription, Cost

Table 3 – Part #2 of Level of Information Need "Felipe Moreira's BIM A+ Dissertation"

Geometrical Information					
Element	**Detail**	**Dimensionality**	**Location**	**Appearance**	**Parametric Behavior**
Walls, Columns, Floor and Ceiling	Simplified	3D	Relative	Simplified	Not requested
Doors, Windows, Desks, Storage Unit, and Computer	Simplified	3D	Relative	Simplified	Not requested

Main elements such as walls, columns, floor, and ceiling, required minimal alphanumeric information, mainly consisting of **identification** details like name and description. This information was sufficient for basic asset management and categorization within a breakdown structure.

For replaceable assets like doors, windows, desks, storage units, and computers, similar simple **identification** information was necessary, including name, description, and tag number. Furthermore, the model incorporated essential **information content** for operation and maintenance purposes. This included details such as the manufacturer's name, manufacturer URL, installation date, warranty start date, warranty description, and cost. This comprehensive set of information ensured that the AR-enhanced tool could support asset maintenance effectively, enabling users to make informed decisions and carry out necessary maintenance activities with ease.

The **detail** was intentionally simplified, focusing primarily on the outer shell of the objects. For facility management needs, detailed elements were not deemed essential. However, for optimal 3D visualization within the AR-enhanced tool, a certain level of simplicity was preferred. The **dimensionality** of the model is set to 3D to facilitate visualization within the AR-enhanced tool. The **location** of all objects in the model is defined as relative, as it was modeled using alignments and grids derived from a point cloud. This approach ensures that the objects are accurately positioned in relation to each other and the real-world environment. The model maintains spatial consistency by using relative coordinates, making it easier to manage and navigate within the AR-enhanced tool. The **appearance** of objects in the model

was deliberately simplified, with a preference for symbolic representation to fulfill facility management requirements. However, it was recognized that this level of detail would not be sufficient for effective visualization in the AR-enhanced tool. Simplified appearance ensures that users can interact with and explore the BIM objects, while still meeting the demands of facility management operations. **Parametric behavior** was intentionally excluded from the model, as it was not a specific requirement for the AR-enhanced tool. The focus of the tool's interaction was on visualizing, accessing metadata, and exploring BIM objects in real-time, rather than enabling users to edit the shape, position, or orientation of the objects. Therefore, the model was designed without parametric capabilities, ensuring that it serves its intended purpose effectively for facility management and AR-based visualization.

4.4. BIM MODEL CREATION

The alignment process, carried out within the BIM authoring platform, made use of the software's tools to manually match the crafted model with the point cloud data. This meticulous procedure ensured that the BIM model accurately represented the physical elements within the facility. Our primary goal was to achieve an approximate accuracy level of 1 cm, a crucial aspect for creating a highly dependable representation of real-world attributes in the digital model. The successful alignment of the point cloud data and the Revit model is visually demonstrated in the following Figures, which provide multiple views of this integration of these two datasets. The point cloud's precise measurements harmoniously blended with the manually created model, resulting in a comprehensive and accurate BIM representation of EQS Global's facility.

Figure 41 – 3D View of of Aligned Revit Model with Point Cloud
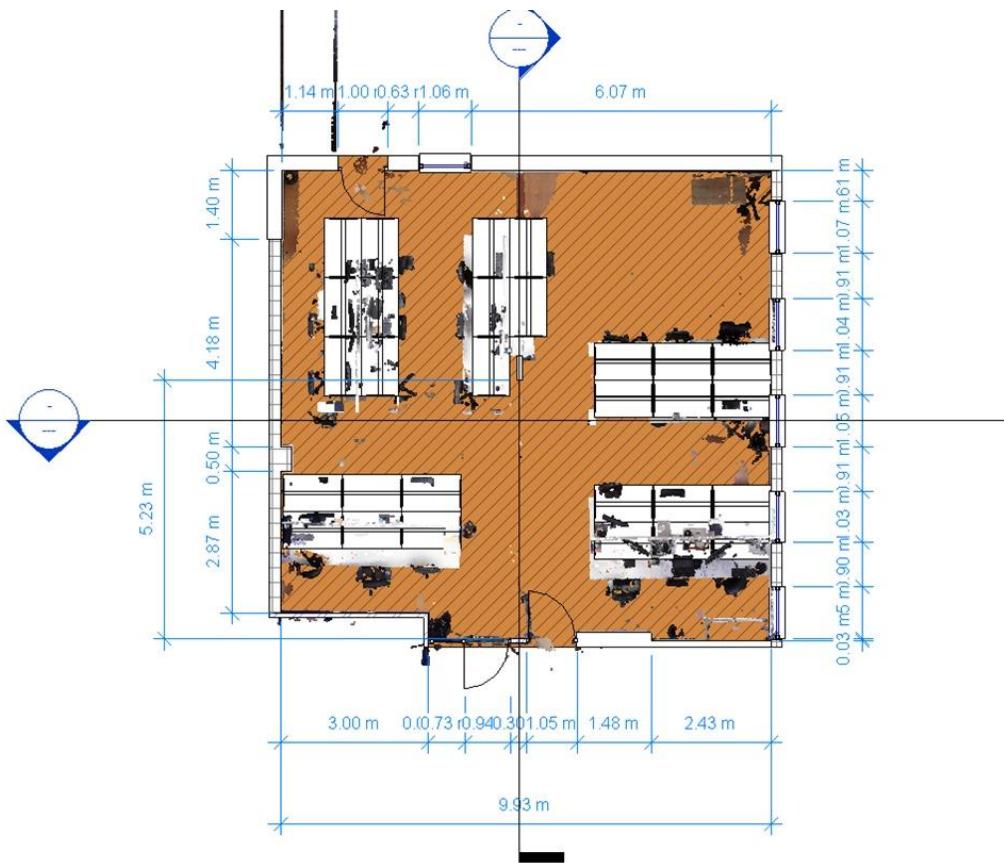
Figure 42 – Top View of Aligned Revit Model with Point Cloud

Figure 43 – Inside View of Aligned Revit Model with Point Cloud

Through the adoption of this chosen surveying and modeling process, EQS Global successfully obtained a comprehensive and precise model, laying the foundation for an accurate and dependable BIM representation. The alignment of the laser scan data with the Revit model ensures that the resulting BIM model effectively encapsulates the real-world attributes of the facility, a critical prerequisite for conducting accurate testing of the Web-Based AR Application for BIMFM.

The subsequent Figures provide a visual representation of the finalized BIM Model and its striking resemblance to the actual EQS office. The conclusive results of the model, exported in the IFC file format, are prominently displayed in Figure 44 and Figure 45, offering a direct visual comparison with their respective real-life office counterparts.
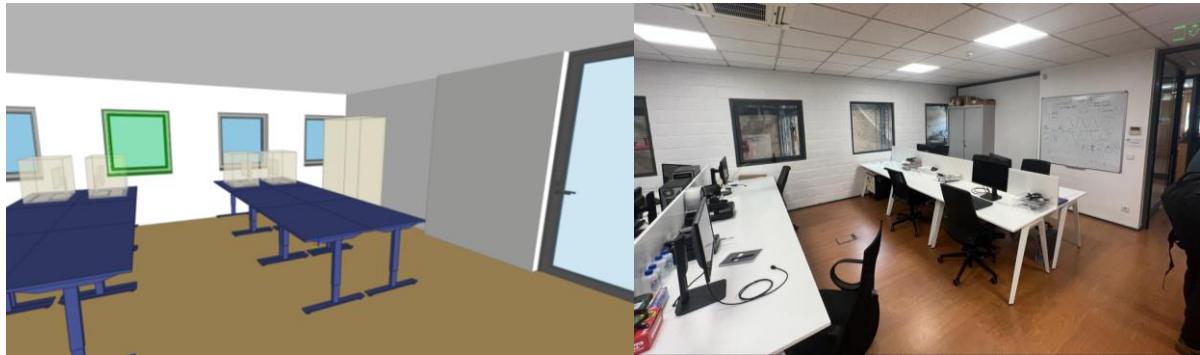
Figure 44 – View #1 of Final BIM Model in IFC Format, compared to Real-Life EQS Global Office

Figure 45 – View #2 of Final BIM Model in IFC Format, compared to Real-Life EQS Global Office

4.5.   IFC EXPORT SETUP

As stipulated in the Level of Information Need, the inclusion of Asset Management parameters became imperative for all objects featured in the model. To streamline this process, the DiRootsOne plug-in was utilized to efficiently assigning all specified parameters. Through the use of this tool, the document shown in Figure 46 was created with all parameters defined in the Level of Information Need.

Figure 46 – File created to organize parameters through DiRootsOne Plug-in

Subsequently, this file was filled out manually and then reintegrated into Revit, automating the assignment of the desired properties to all objects within the model. Following a final review, the model stood prepared for export into an open data format – the IFC file format. As mentioned in Subsection 2.2.3, IFC2X3 is the most widely used version and is the one compatible with IFC.js, which is why it was chosen as the IFC version of the model. Upon export, the option "Export schedules as property sets" was checked to make sure all specified properties went through successfully to the IFC. A final subsequent review was undertaken to ensure that no significant information loss had occurred, as illustrated in the ensuing Figures.
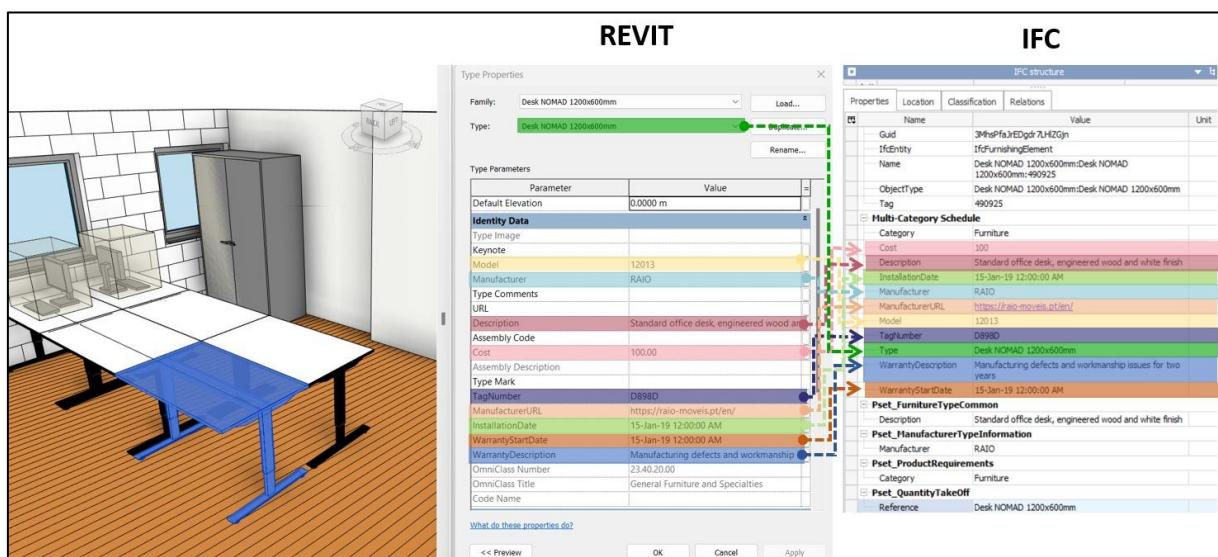
Figure 47 – Test #1 Ensuring no Information loss
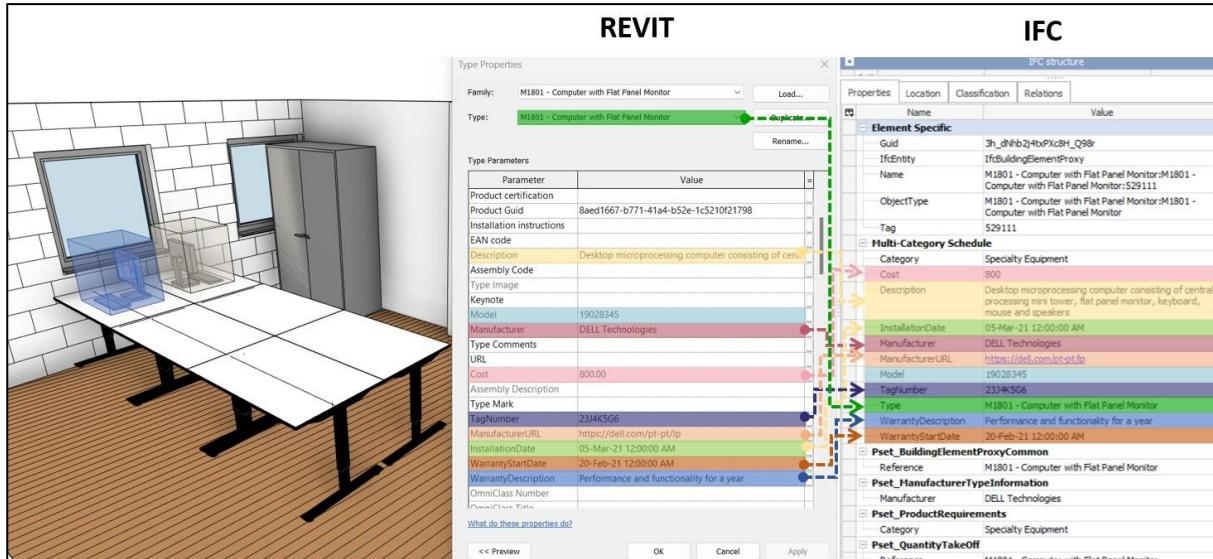
Figure 48 - Test #2 Ensuring no Information loss

Upon completing this validation process, it was ascertained that all requisite information had been successfully exported, obviating the need for any further steps to recover potentially lost data.

4.6. EVALUATION OF THE APPLICATION WITH THE CASE STUDY

Following the creation of the BIM Model in the IFC file format, it was integrated into the "assets" folder of the application, marking the beginning of the final testing phase, located at EQS Global's office premises. This integration granted immediate accessibility to manipulate the model via web browsers on both computers and mobile phones. Through the mobile phone interface, the actual AR environment underwent testing, with an initial evaluation of the model in a reduced size, yielding results as presented in Figure 49. The source code to test the experience first-hand can be accessed on GitHub: https://github.com/Felipemore96/BIM-A-Dissertation.
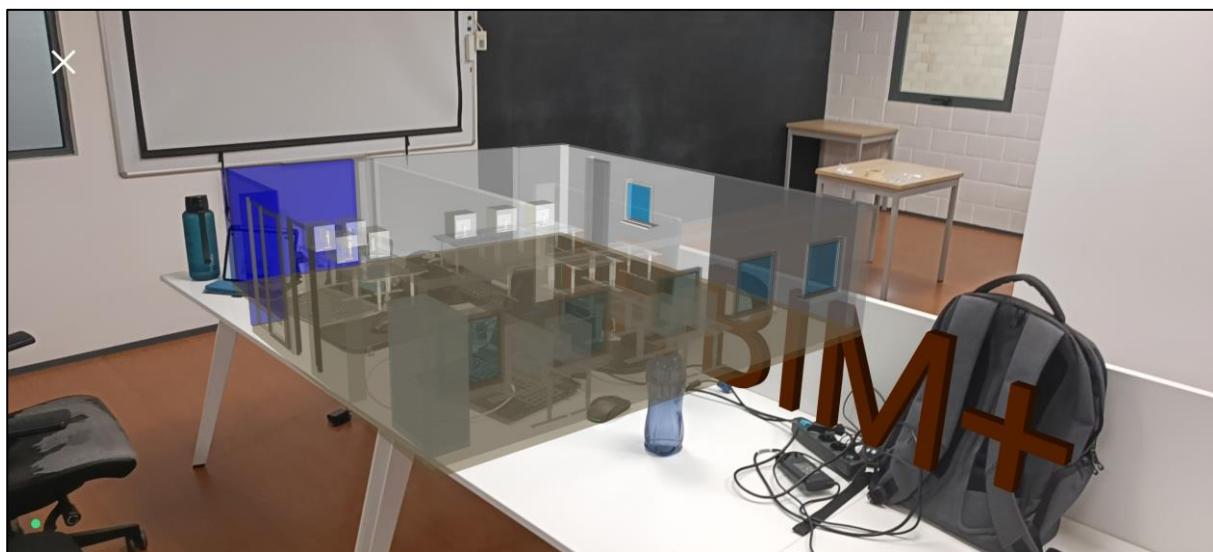
Figure 49 – First Test of AR Implementation with the BIM Model

During this phase of the testing process, the utilization of a local development server became pivotal, offering the developer complete freedom to fine-tune the exact basepoint of the model until it achieved a perfect alignment with the real-world facilities. A QR image was loaded into the "assets" folder and printed, with coding indicating the exact location where this image should align within the model. Following the initial tests, the model was restored to its normal size. Through a process of trial and error, the position 'position.makeTranslation(10, 0, 5);' was selected as the base point for the model, closely mirroring the QR's location within the physical office. Once this alignment process was completed, the model's integration into AR became entirely automatic, eliminating the need for any further adjustments to the model's location or dimensions. The real QR print, employed in conjunction with image tracking technology to position the entire model, is presented in Figure 50.
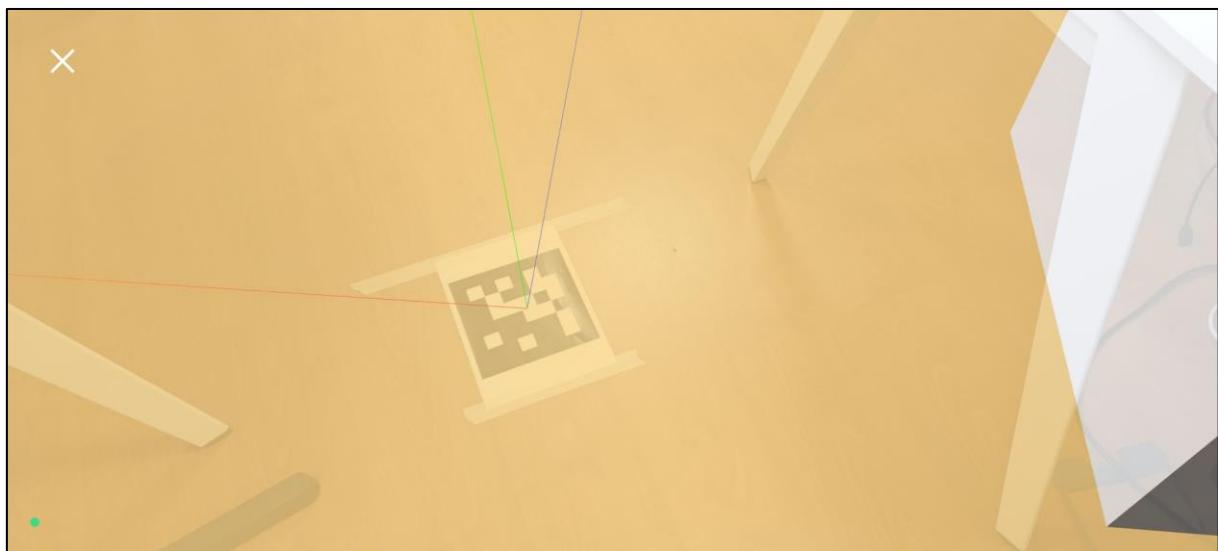
Figure 50 – QR image placed in the center of the office for adequate Image Tracking

The AR environment was now complete, with the virtual model closely matched the real office. This enabled users to manipulate their devices, exploring the real and virtual elements from various angles, as exemplified in Figure 51. The integration of real-time updates based on user interactions added dynamism and engagement to the experience.
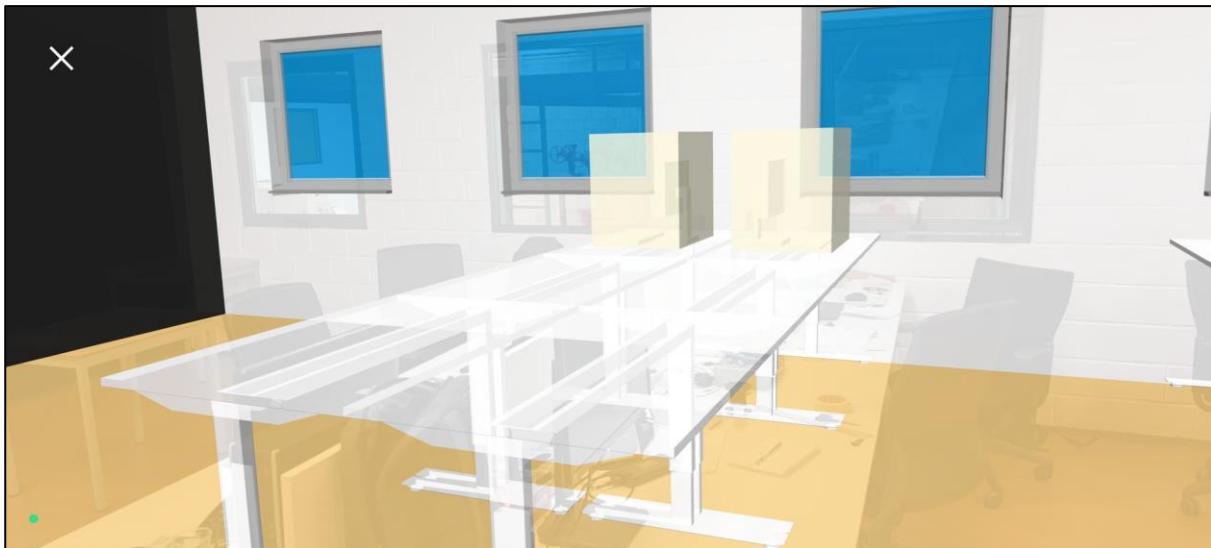
Figure 51 – Real and Virtual object aligned with Image Tracking

The last functionality to be tested was Dynamic Data Access, made possible through the implementation of the raycasting mechanism. This feature allowed users to click on objects in the computer, or tap on objects on mobile, to receive instant feedback through object selection and highlighting. The testing process involved selecting a set of properties and specifying them in the code to evaluate their visibility in the AR environment. The first test aimed to retrieve warranty descriptions, manufacturer details, descriptions, names, IFC entities, and custom text for a computer. A second test was also conducted, aiming to visualize installation dates, manufacturer information, IFC entities, GUID codes, and a custom text. Results obtained from those respective tests are depicted in Figure 52 and in Figure 53.

Figure 52 – Test #1 of Dynamic Data Access in AR Environment
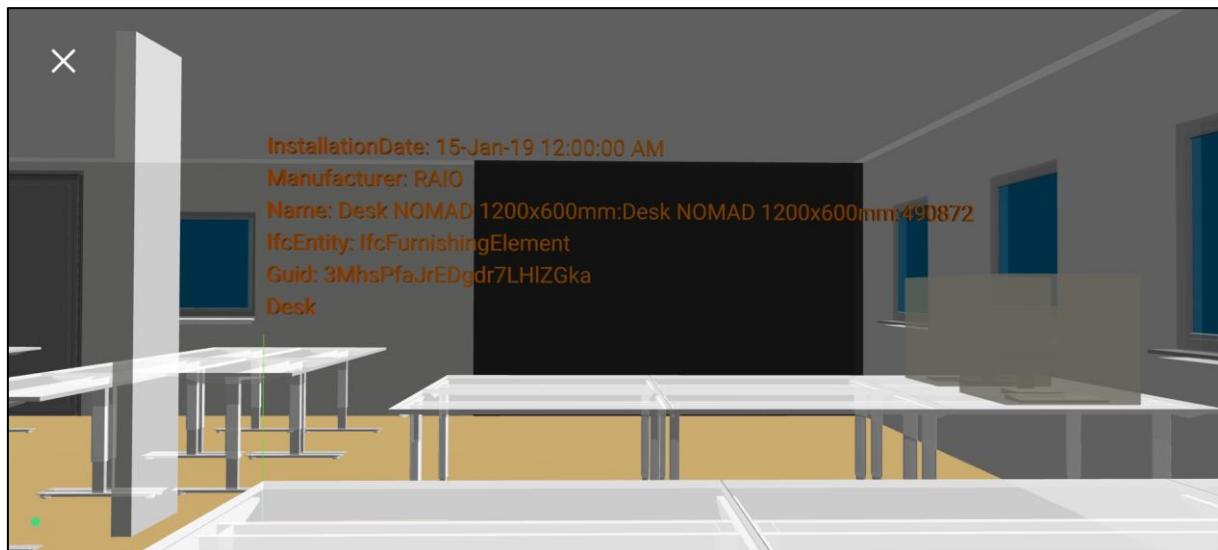
Figure 53 – Test #2 of Dynamic Data Access in AR Environment

Based on these demonstrations, it can be confidently concluded that the designed application's functionalities were successfully tested and validated. This comprehensive assessment provided valuable insights into the application's interaction with a real BIM Model and addressed specific usability tests in the field of facility management. While certain options and interface features may require further optimization for an ideal user experience, the primary objective of creating a Web-Based AR Application for BIMFM was achieved, all within the framework of open-source software and showcasing wide customization options for the developer.

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5. CONCLUSIONS

In the pursuit of leveraging the potential of AR technologies in the AECO industry, this research centers on the creation of an accessible Web-Based AR Application for BIMFM that integrates BIM information through the potential of open format options like WebXR and IFC. The primary objective was to establish an independent framework, reducing reliance on third-party solutions and proprietary alternatives, thereby empowering users within the construction industry with a versatile and cost-effective tool that enhances collaboration, decision-making, and productivity.

The development process commenced with the creation of a BIM Model in the IFC file format, a critical step that laid the foundation for subsequent testing and validation. This model was integrated into the application, offering immediate accessibility for manipulation via web browsers on both computers and mobile phones. Through the mobile phone interface, the AR environment underwent several tests, with an initial evaluation of the model's reduced size.

The utilization of a local development server during the testing phase proved highly advantageous, affording the developer the flexibility required to fine-tune the model until it achieved alignment with real-world facilities. Image tracking played a very important role in this process, with a QR image serving as the indispensable reference point for aligning the virtual model with the physical office space. Through a series of rigorous tests and meticulous adjustments, the successful integration of real and virtual elements was achieved.

Notable room for improvement was noted in the area of real-time updates. The application demonstrated good responsiveness to camera movements; however, it occasionally exhibited deviations from its initial loaded position, resulting in a constant drift by a few centimetres. It is important to acknowledge the potential influence of the device's quality and processing power on this behavior. Nevertheless, the nature of AR technology suggests that this aspect will likely improve with the advent of new API versions similar to WebXR. Modern tools such as AI (Artificial Intelligence) hold promise for enhancing the system's understanding of real-world facilities and objects. Additionally, ongoing advancements in motion sensors within everyday mobile devices are inevitable, a factor that warrants consideration, especially given that the mobile device used for this dissertation was suboptimal.

Dynamic Data Access, implemented through the raycasting mechanism, marked the final functionality to be tested. This feature allowed users to interact with objects in the AR environment, receiving instant feedback through object selection and highlighting. Tests were conducted to retrieve various properties and data related to objects within the BIM Model, demonstrating the application's ability to provide real-time information based on user interactions. Opportunities for refinement within this specific functionality primarily revolve around the process of transforming IFC information into a format compatible with Three.js. Future research could delve deeper into finding an optimal approach to import the IFC file while preserving both geometrical and non-geometrical properties for each object.

An inherent advantage of harnessing WebXR based on IFC for AR lies in the remarkable customizability it offers within the AR environment. This flexibility not only serves to minimize subscription and licensing expenses but also empowers users to fine-tune their FM tools without the burden of software costs. The application's remarkable compatibility across a wide spectrum of platforms, including mobile

phones, HMDs, and smart glasses, ensures its accessibility for users across diverse devices and operating systems.

Furthermore, the utilization of the IFC file format eliminates the need for convoluted conversions and plugins, ensuring data integrity and accessibility across multiple platforms. The ease of integration with diverse operating systems, by operating through web-browser and without need of installing applications, accentuates the tool's practicality and reach.

Having successfully tested and validated all proposed functionalities, valuable insights has been gained into how the application interacts with real BIM Models and its usability in the field of facility management. While it is evident that certain options and interface features may necessitate further optimization to deliver an ideal user experience, the primary goal of creating a Web-Based AR Application for BIMFM has been effectively realized. This achievement was made possible within the open-source software framework, offering developers the flexibility of customization without incurring costs.

Nevertheless, the testing process shed light on numerous functionalities that warrant consideration for future implementation. Some general ideas encompass the ability to edit object properties, move objects within the AR environment, alter the geometrical properties of objects with real-time feedback, and adjust the transparency of virtual objects in real-time to grant users greater control over their position in the XR spectrum, bridging the gap between the real and virtual environments. Furthermore, features commonly found in traditional IFC visualization tools, such as adding cutting planes, obtaining precise measurements of distances, areas, and volumes, or accessing exact coordinates, could be incorporated.

As the concluding chapter of this research, this section leaves the door open to a multitude of questions for future exploration. How can this tool further evolve to accommodate evolving AR technologies? How can it be integrated into existing construction workflows to maximize its impact? Results obtained in this research possess substantial potential not only for enhancing FM practices but also for enhancing various phases of a construction project's life-cycle, including actual construction processes, planning phases, and general training. The provision of real-time access to visualize, manipulate, and explore critical BIM objects alongside their associated metadata has been demonstrated to foster enhanced collaboration, improved decision-making, and increased productivity. These findings are not only valuable for practitioners within the construction domain but also for researchers and educators seeking to empower the industry with innovative solutions, leveraging AR's proven utility in fields such as education and medicine.

In closing, this dissertation marks a significant step towards self-sufficiency and community-driven progress. The insights presented in this work can be considered as a small step in a big process towards self-sufficiency and community-driven progress, harnessing technology for the betterment of the construction industry. By fostering comprehensive research and enabling interconnected studies within the BIM community, this framework sets the stage for a culturally independent and empowered ecosystem, possibly even evolving into a competitive force in comparison to current existing technologies.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEC	Architecture, Engineering, and Construction
AECO	Architecture, Engineering, Construction, and Operation
AI	Artificial Intelligence
AM	Asset Management
API	Application Programming Interface
AR	Augmented Reality
BARMS	BIM-based Augmented Reality Maintenance Software
BIM	Building Information Modelling
CH	Cultural Heritage
CPU	Central Processing Unit
CPVR	Cross-Platform Framework
CSS	Cascading Style Sheets
ERP	Enterprise Resource Planning
FM	Facility Management
FBX	Filmbox file
GLTF	GL Transmission Format
GPS	Global Positioning System
GPU	Grapghics Processing Units
HMD	Head Mounted Display
HNC	Head and Neck Cancer
HTML	HyperText Markup Language
IFC	Industry Foundation Classes
IoT	Internet of Things
ISO	International Organization for Standardization
JS	JavaScript
LED	Light-Emitting Diode
LOD	Level of Development
JSON	JavaScript Object Notation
MR	Mixed Reality
NoSQL	Not Only Structured Query Language
NUI	Natural user Interactions
OBJ	Object file
OOP	Object-Oriented Programming
O&M	Operation and Maintenance
RAM	Random Access Memory
REST API	Representational State Transfer Application Programming Interface
SDK	Software Development Kit
SLAM	Simultaneous Localization and Mapping
SQL	Structured Query Language
VR	Virtual Reality
VS Code	Visual Studio Code
WebGL	Web Graphics Library
XR	Extended Reality