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USING METAVERSE TO IMPROVE BIM PROCESSES

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UPORABA OKOLJA METAVERZUM ZA IZBOLJŠANJE PROCESA INFORMACIJSKEGA MODELIRANJA ZGRADB

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Izvleček: V zadnjih letih je bil dosežen velik napredek v uveljavitvi informacijskega modeliranja zgradb (andl. Building Information Modeling - BIM), zato je potrebno to novo energijo v gradbeništvu izkoristiti ter nadaljevati z digitalizacijo gradbene industrije. BIM se mora razvijati in prilagajati z integracijo novih informacijskih tehnologij. Cilj raziskovalne naloge je poiskati in oceniti priložnosti, ki jih omogoča metaverzum v kontekstu procesa BIM za načrtovanje, informacijsko upravljanje ter sodelovanje. Metaverzum je 3D virtualno okolje, ki združuje različne informacijske tehnologije z namenom zagotoviti možnosti za ustvarjanje in sodelovanje. V tem kontekstu raziskovalno delo predstavi različne informacijske tehnologije, ki so običajno del metaverzuma ter najpogostejše uporabniške scenarije uporabe metaverzum okolij v različnih industrijah, še posebej v gradbeništvu.

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Abstract: The technological rigidity that characterizes the Architecture, Engineering, Construction, and Facility Management (AECO/FM) industry is the starting point for this academic work. Although Building Information Modeling/Management (BIM) is the start of something new, it should not be regarded as the end. There is a need for BIM to adapt, develop, and mature through integration with emerging technologies. Therefore, this research aims to investigate and identify the potential applications of the metaverse to improve BIM processes for design, information management and collaboration. Metaverse is a three-dimensional virtual world that combines digital technologies to produce data that is reliable, transparent, and traceable. To fully embrace connected construction, which is one of the main goals of Construction 4.0, it is thought that AEC/FM professionals should start communicating and collaborating in the metaverse, making it a new normal. Therefore, this study highlights the importance of metaverse and its use cases in various industries, particularly in the AEC/FM sector.

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TABLE OF CONTENTS

ERRATA III

Acknowledgements V

Bibliografsko – Dokumentacijska Stran in Izvleček VII

Bibliographic - Document Information and Abstract IX

Table of Contents XI

Index of Figures XIII

Index of Graphs XV

1 Introduction 1

1.1 BIM - A revolutionary approach 1

1.2 How is BIM transforming the AEC/FM industry? 2

1.3 Challenges and Problems 5

1.4 Problem Statement 7

1.5 Research Objective 8

2 Literature Review 10

2.1 Introduction to Web 3.0 10

2.2 Construction 4.0 - An overview 12

2.3 Technological developments to enhance construction processes 14

2.3.1 Cloud Computing 14

2.3.2 Internet of Things 16

2.3.3 Extended Reality 17

2.3.4 Blockchain Technology 18

2.3.5 Digital Twins 20

2.4 Future Developments 22

3 Metaverse - History, Overview, and Evolution 23

3.1 Why should the metaverse be explored? 25

3.1.1 Working remotely - A new normal 25

3.1.2 Massive Economic Opportunity ... 29
3.2 Layers of Metaverse ... 30
3.3 The current state of Metaverse ... 32
3.3.1 Decentraland ... 32
3.3.2 Cryptovoxels ... 32
3.3.3 The Sandbox ... 33
3.3.4 Somnium Space ... 33
3.4 How does metaverse relate to BIM? ... 34
4 Use cases, applications, and benefits of the metaverse ... 36
4.1 Use cases and application of metaverse in various industries ... 36
4.1.1 Enhanced Social Media Experience ... 36
4.1.2 Immersive Sales & Marketing ... 37
4.1.3 Revolutionized Remote Working and Online Education ... 37
4.1.4 Advanced Blockchain Applications ... 38
4.1.5 The Future of Entertainment ... 38
4.1.6 Realistic Online Gaming ... 38
4.2 The potential benefits of metaverse to the AEC/FM industry ... 39
5 Discussions ... 41
6 Conclusions and Recommendations ... 44
7 References ... 46

INDEX OF FIGURES

FIGURE 1: OVERVIEW OF BIM PROCESSES FROM 1D TO 7D - SOURCE: (PROTIM) 2
FIGURE 2: BRIEF INSIGHT ON COUNTRIES LEADING THE WAY IN BIM ADOPTION - SOURCE: (UNITED-BIM)..................3
FIGURE 3: STAGES OF BIM MATURITY - SOURCE: (SUCCAR, 2013)..6
FIGURE 4: UNDERSTANDING THE SPATIAL WEB - SOURCE: (V. COOK ET AL., 2020) 10
FIGURE 5: THREE TIERS OF IT INFRASTRUCTURE AND BUILDING THE SPATIAL WEB - SOURCE: (V. COOK ET AL., 2020) 11
FIGURE 6: THE PATH TO THE MATURITY OF A SPATIAL WEB - SOURCE: (V. COOK ET AL., 2020)..............................12
FIGURE 7: CONSTRUCTION 4.0 FRAMEWORK - SOURCE: (SAWHNEY ET AL., 2020) 14
FIGURE 8: A GENERAL REPRESENTATION OF CLOUD COMPUTING ARCHITECTURE - SOURCE: (PATIL AND BASUMALLICK, 2022)..15
FIGURE 9: APPLICATIONS OF EXTENDED REALITIES (XR) IN DESIGN AND CONSTRUCTION - SOURCE: (ALIZADEHSALEHI, HADAVI AND HUANG, 2020) 18
FIGURE 10: DISTRIBUTED LEDGER SYSTEM IN AEC/FM - SOURCE: (BRICKSCHAIN) 19
FIGURE 11: INFORMATION FLOW FROM BIM TO DIGITAL TWINS - SOURCE: (MERCER, 2020) 21
FIGURE 12: EVOLUTION OF METAVERSE - SOURCE: (HUYNH-THE ET AL., 2022) 24
FIGURE 13: CONNECTED CONSTRUCTION IN THE METAVERSE - SOURCE: (BIMENGUS) 28
FIGURE 14: SEVEN LAYERS OF THE METAVERSE - SOURCE: (NJOKU ET AL., 2022)...31
FIGURE 15: IMPORTING 3D MODEL TO DECENTRALAND - SOURCE: (BY AUTHOR) 32
FIGURE 16: THE USER INTERFACE OF VARIOUS METAVERSE PLATFORMS; SANDBOX (TOP LEFT), SOMNIUM SPACE (TOP RIGHT), DECENTRALAND (BOTTOM LEFT), AND CRYPTOVOXELS (BOTTOM RIGHT).......................................35
FIGURE 17: AN OVERVIEW OF NVIDIA OMNIVERSE FOR DESIGN COLLABORATION - SOURCE: (NVIDIA OMNIVERSE) ..40
FIGURE 18: BIM PROCESSES IN THE METAVERSE - SOURCE: (BY AUTHOR)...41
FIGURE 19: REVIT MODEL AND EDITING ENVIRONMENT (LEFT) VS ROBLOX GAME AND MODELLING ENVIRONMENT (RIGHT) - SOURCE: (REVIT MODEL/SCREENSHOTS BY LUKA GRADIŠAR, ROBLOX MODEL/SCREENSHOTS BY ERIN DOLENC) 44

» This page is intentionally blank «

INDEX OF GRAPHS

GRAPH 1: COMPARISON OF BIM ADOPTION ACROSS THE DIFFERENT SECTOR IN THE AEC INDUSTRY - SOURCE: (DODGE SMARTMARKET, 2022)....4
GRAPH 2: A POST-COVID STATISTICAL INSIGHT ON REMOTE WORK - SOURCE : (FLEXJOBS.COM) 26
GRAPH 3: CHALLENGES AND ISSUES FOR AEC/FM PROFESSIONALS WITH REMOTE WORK - SOURCE: (ARCHITIZER)...27

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1 INTRODUCTION

The development of digital technologies offers many benefits in boosting the performance of the Architecture, Construction, Engineering and Facility Management (AEC/FM) industry. Despite the terrible adoption rate, digitalization in AEC/FM has improved task realization, communication, processes, collaboration, and the use of information. With the introduction of the fourth Industrial revolution (or Industry 4.0), many changes have been observed in the construction sector (King, 2017). New workflows are emerging with the advent of digital technologies, which tend to be much more innovative than those conventional approaches used in the past. The use of these technologies is bringing revolution not only in design and construction but also in operation and maintenance. Digitalization improves efficiency and the use of resources by expanding access to relevant information, working collaboratively, and rapidly resolving issues during the lifecycle of a project.

This research is aimed to shed light on recent technological advances and their impact on the AEC/FM sector. A summary of research articles published in the past few years reporting on the experiences and achievements of digital technologies applied to construction has been carried out. It turns out that the integration of technological developments into the construction sector has brought new features and insights to businesses (Joblot *et al.*, 2021). Many of them were not originally claimed with the sole implementation of a BIM methodology. In response, engineering and construction businesses plan to invest five percent of annual revenue in digital operations (Geissbauer, Vedso and Schrauf, 2016). These latest opportunities eventually raise the question of how they might impact the speed of digital transformation in this sector.

1.1 BIM - A revolutionary approach

Building Information Modelling (BIM) is the holistic approach of creating and managing information from a concept to operation. It encourages all the stakeholders to be actively involved in the project. In his BIM Framework blog, Bilal Succar defines BIM as "a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a facility" (Succar, 2013). Following this workflow, the BIM model gets enriched with information and develops itself into an asset. This information can help us to present the built asset, in all its dimensions, following a way that is entirely transparent. **Figure 1** gives a brief overview of how BIM model evolves from a concept/idea (1D) to the facility management (7D).

Over the last few years, the establishment and implementation of Building Information Modelling (BIM) with the help of digital technologies has completely transformed the architecture, engineering, construction, and facility management (AEC/FM) industry. The introduction of BIM added innovative strategies to the design, construction, and operation phases. It has, furthermore, introduced new ways of collaboration amongst stakeholders throughout the project's lifecycle (Sacks *et al.*, 2018). Researchers have confirmed that adopting BIM tools and workflows boosted design productivity, reduced production waste, and enhanced connectivity. To benefit from BIM, it is necessary for a client/owner to indicate the deliverables at the start of the project, and they ought to be delivered by the project team in line with the agreed requirements (Succar and Kassem, 2016). Information management, therefore, turns out to be one of the fundamental focuses of BIM strategies.

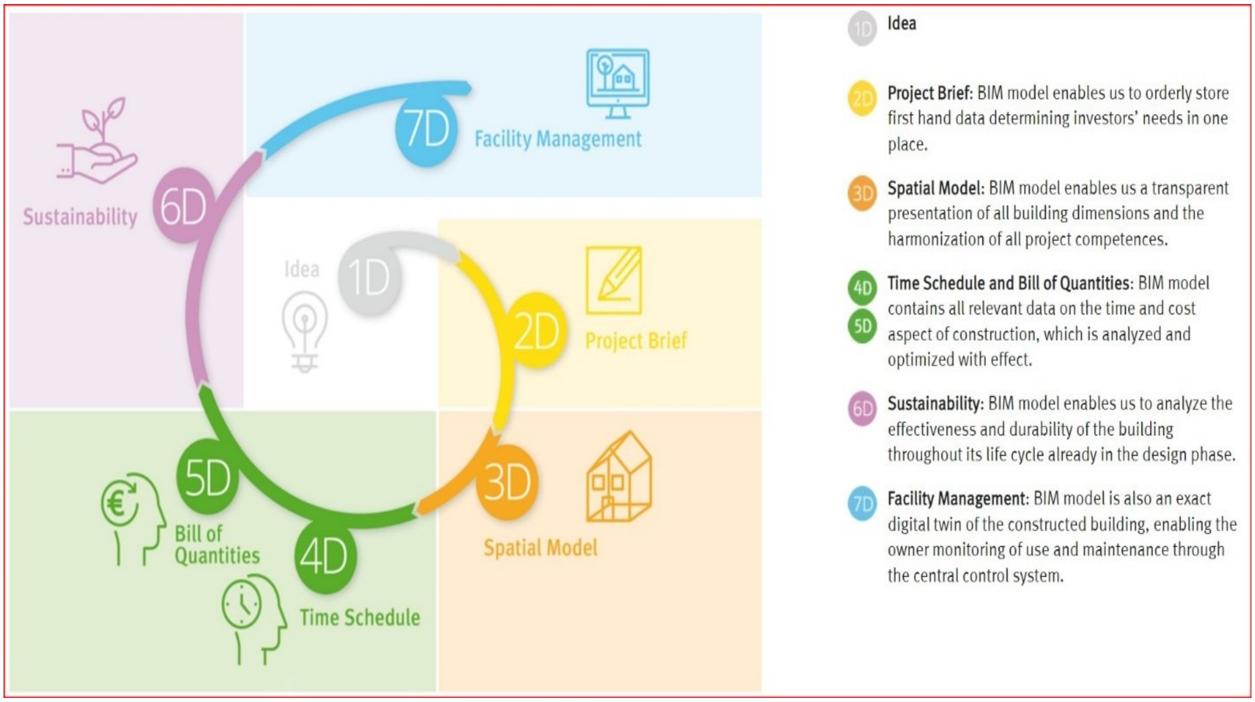


Figure 1: Overview of BIM processes from 1D to 7D - Source: (Protim)

1.2 How is BIM transforming the AEC/FM industry?

The AEC/FM industry adds around 10% to the overall economy of the world. It promotes economic growth, offers mass employment, and acts as a bridge between other industries and the overall economy. BIM enables rapid transformation in the Architecture, Engineering, Construction, and Facility Management (AEC/FM) industry, encouraging business development and driving positive outcomes. The organisations that embraced BIM and paved the way for digital transition observed increased productivity. However, many companies in the industry are still in the early stages of BIM adoption. With the help of dodge data & analytics, SmartMarket has published a new report titled "Accelerating Digital Transformation Through BIM". This report reveals both the scale of BIM transformation and the challenges holding back some companies. The disparities in results and return on investment are increasingly evident between companies deeply committed to BIM across most projects and those in the early stages of BIM adoption.

Every day, the world around us is becoming more technologically advanced. With the rise in urbanization and the growing trend toward smart cities, all the world's major countries have started calling for BIM adoption. BIM adoption can assist the country in laying a solid infrastructure foundation, allowing it to set an example for others to follow. **Figure 2** gives an insight into countries leading the way in BIM adoption.

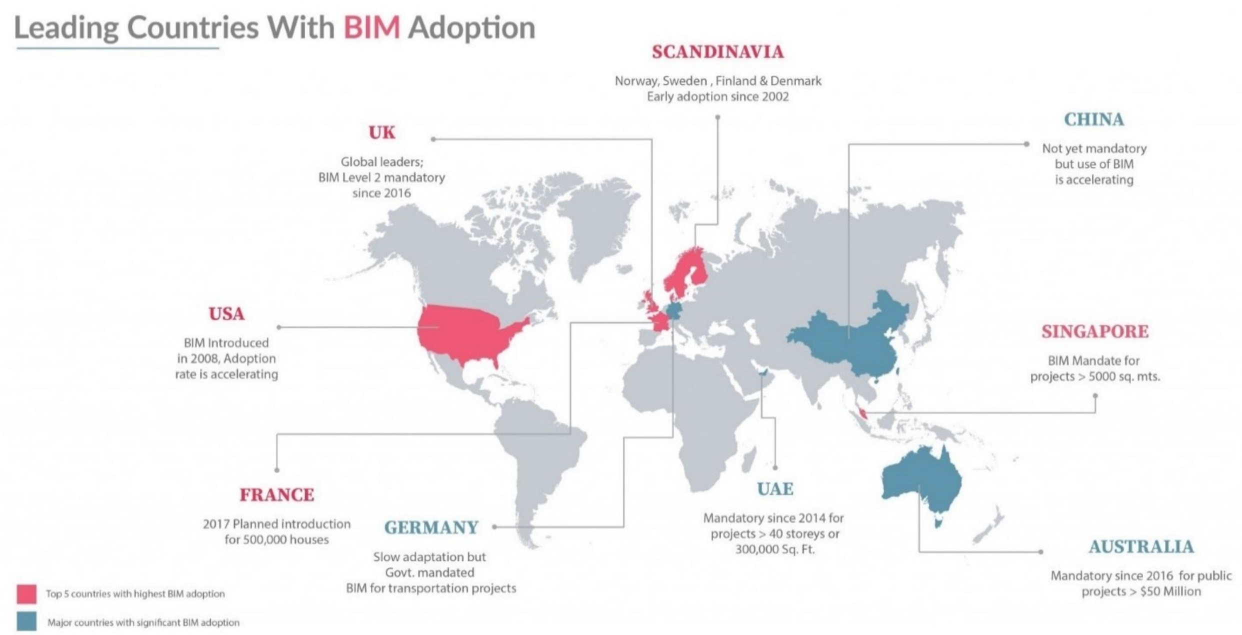
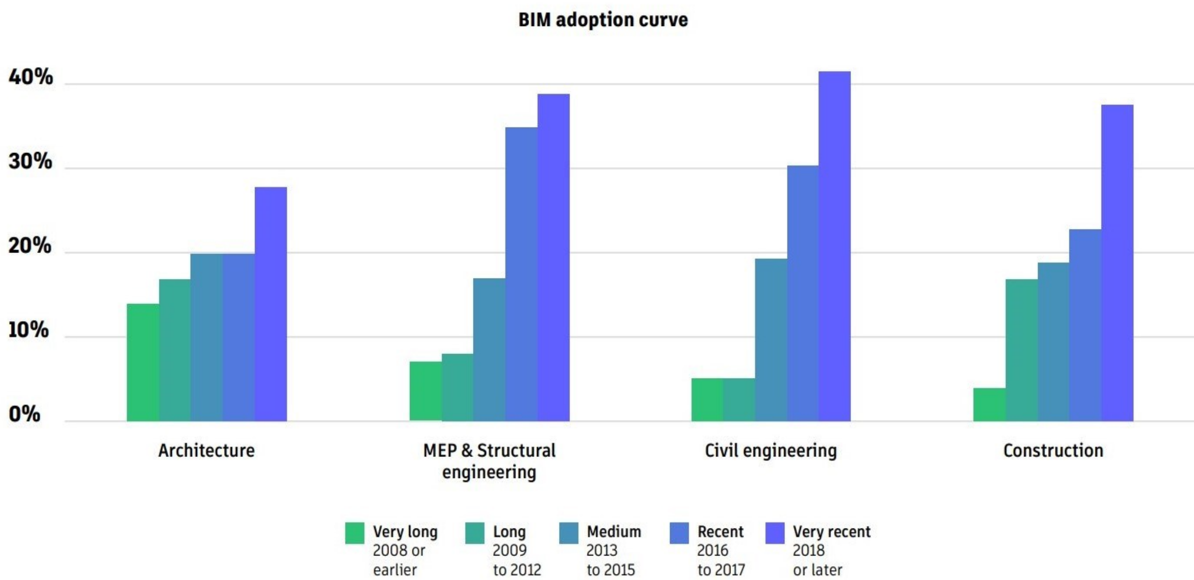


Figure 2: Brief insight on countries leading the way in BIM adoption - Source: (United-BIM)

Dodge data & analytics collected data through an online survey from a total of 843 respondents, spanning companies of various sizes directly related to the AEC sector and located in different parts of the world, to determine the industry's position in the digital transition and the value of BIM in this evolution. The adoption of BIM is speeding up across the industry. The researchers at Dodge Analytics discovered that BIM is quickly becoming mainstream in the AEC industry. It was observed that the architectural businesses adopting BIM practices have evolved over the years. In addition, engineering and construction companies are embracing BIM at an unprecedented rate (Dodge SmartMarket, 2022). **Graph 1** shows an increase in BIM adoption across various sectors in the AEC industry.

BIM-enabled companies are incorporating BIM practices into an increasing number of projects. The recent Dodge SmartMarket report is unequivocal. With BIM, the industry has reached a tipping point. Most of the companies use BIM on fifty percent or more of their projects (Dodge SmartMarket, 2022). Furthermore, the depth of a company's BIM engagement is directly related to the claimed BIM benefits. BIM values the outcomes that matter most to AEC companies. Firms with established BIM practices are well-positioned to take advantage of new tools and technologies as they become available. According to this report, the direct relationship between the increased intensity of BIM usage with the number of years in practice serves as strong evidence of the long-term value of BIM. Many firms that use BIM are now integrating it into at least half of their projects, with a marked increase forecast of BIM usage in the next 2-3 years (Dodge SmartMarket, 2022).



Graph 1: Comparison of BIM adoption across the different sector in the AEC industry - Source: (Dodge SmartMarket, 2022)

Investing in BIM training is essential in optimizing BIM for integrated digital workflows in internal and external collaborative processes. Using BIM consistently over time leads to a better understanding of its critical contributions to boosting multi-stakeholder collaboration and improving outcomes for all the parties involved in the project (Dodge SmartMarket, 2022). It has been observed that interest in highly collaborative processes is widespread across the industry. Moreover, there appears to be a direct relationship between optimizing technology investments and areas where BIM training is more prevalent (Dodge SmartMarket, 2022).

A commitment to process and implementation increases return on investment (ROI). As firms become more skilled at BIM and increase the intensity of their implementation, they reap greater benefits. Architects were among the first to adopt BIM, and they continue to record the best return on investment from their BIM practices. It should be no surprise that late-adopter civil engineers have seen similar results from their investments in BIM-first processes (Dodge SmartMarket, 2022). This suggests that BIM ROI is driven as much, if not more, by the intensity of use as it is by the age of practice. Many companies across all industries report a positive return on their BIM investments, with Civil Engineers and Architects reporting the highest returns (Dodge SmartMarket, 2022).

When asked to rate the advantages of effectively imposing BIM practices, architecture and engineering firms reported medium to high growth and success across a wide range of categories (Dodge SmartMarket, 2022). Construction firms and contractors seek various benefits; however, their overall satisfaction with the outcomes is consistent with what architecture and engineering firms report following the incorporation of BIM practices into their workflows (Dodge SmartMarket, 2022). Similarly, designers and contractors are noticing an overall benefit from BIM implementation in their projects, leading to an increased sense that there is even more added value to be gained from growing BIM intensity.

1.3 Challenges and Problems

Building Information Modelling (BIM) can be defined as a diverse repository of information and knowledge that can be critical to the success of a project and is valuable throughout the project's life cycle, particularly when different stakeholders need to communicate in different ways. On the other hand, it is mainly used during the design and pre-construction phases and less frequently in the later stages of the building life cycle. The complexity of an asset necessitates the adoption of new technologies or tools to assist in managing all this information in BIM, taking BIM one step further in realizing its full potential.

According to Joseph Schumpeter's Theory of Economic Development, an innovative entrepreneur disturbs the equilibrium by bringing technological and organizational innovations that realign to the new reality, a process known as creative destruction. The construction sector has appeared as one of the least digitalized and reluctant to transform, especially concerning digital technologies (Leviäkangas, Mok Paik and Moon, 2017). The advancements in new technologies, such as Cloud Computing (CC), Internet of Things (IoT), Extended Reality (AR, VR and MR), Blockchain Technology (BCT) and Digital Twins (DT), provided a plethora of applications for improvement in the construction industry. However, integrating these technologies into BIM has been slow due to perceived risks and constraints associated with its development. Compared to other industries, such as manufacturing and automotive, one of the most significant challenges in modernizing the construction industry is its unwillingness to embrace technological advancements (Oesterreich and Teuteberg, 2016).

BIM has provided numerous benefits to the AEC/FM industry. For instance, it can facilitate project collaboration by bringing stakeholders closer and providing them with visualization capabilities. As a result, it helps in the synchronization of design and construction plans and detects design inaccuracies. When used correctly, it can impact various aspects, such as cost estimation, schedules, compliance checking, design analysis, and environmental and thermal performance. However, several challenges are encountered using BIM in the AEC/FM industry. For instance, interoperability and integration have been mentioned as vital issues in BIM due to heterogeneous equipment and systems. The inability to seamlessly exchange data limits collaboration in the AEC/FM industry, which ultimately impacts BIM adoption.

Furthermore, one of the factors limiting BIM application is the cost of BIM software tools. (Sun *et al.*, 2017) also mentioned BIM model ownership, model accessibility, data management, data isolation, and data security are some important issues within construction projects. Since BIM has become mandatory in some countries, it is necessary to overcome its limitations within BIM. Integrating digital technologies into BIM can assist in overcoming these barriers to BIM adoption in the AEC/FM industry. An investment in the metaverse has the potential to increase efficiency and reduce numerous issues that are encountered by the construction industry. However, this may take years to complete. There is still a lack of comprehensive understanding of how these technologies are related to BIM and how they can be used holistically to advance future BIM innovations. The possibility of more than one technology working collaboratively with BIM is nearing realization, but it remains an important topic for research.

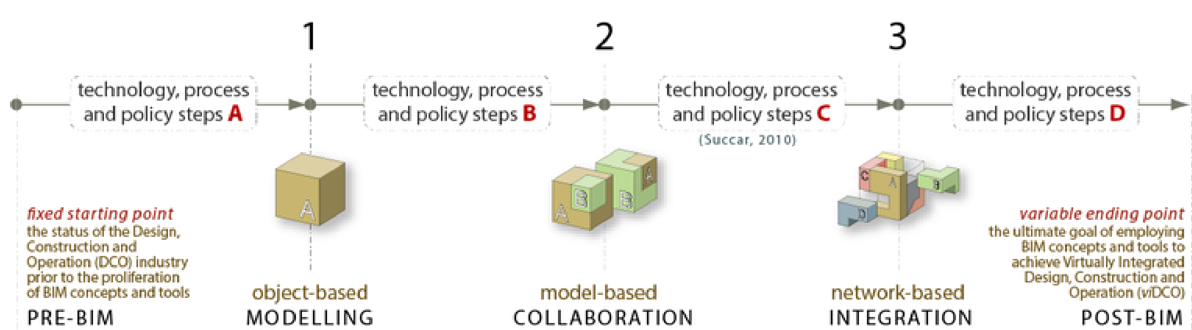


Figure 3: Stages of BIM maturity - Source: (Succar, 2013)

The construction industry is changing the traditional way of doing business, with information now being exchanged digitally instead of on paper. However, the transition has been slow and currently faces many obstacles. The development of the AEC/FM industry is linked with the constant implementation of new technologies. BIM has brought significant added value to the development process of the construction industry. It is regarded as a critical resource for exchanging information among various stakeholders in the AEC/FM industry. For instance, IoT-enabled BIM can examine how a building deteriorates over time. In response, it can help devise an appropriate strategy for maintenance work. However, BIM has not been fully utilized in later design stages. As a result, there is a lack of an overall understanding of what BIM will look like in the future.

Integrated Project Delivery is the aimed level of BIM, a combination of policies, technologies, and processes. It is primarily based on a real-time integrated model in which all disciplines are interdependent and encourage collaboration. **Figure 3** provides input on various stages of BIM maturity. Employing BIM concepts and tools aims to achieve virtually integrated design, construction, and operation. However, in a construction project, a significant volume of data, which can be critical, is left out of the construction project without taking advantage of its untapped value. The construction industry must recognize the significance of this overlooked data because mining and managing massive amounts of data is critical in facility management and can also be useful in future construction projects. Moreover, non-geometric information is as important as geometric information and helps in better decision-making; however, it is often ignored. BIM facilitates the management of information; nonetheless, it must be used in conjunction with new technologies that can embrace digital construction by transforming the construction industry into a dynamic environment.

1.4 Problem Statement

Over the past decade, the AEC/FM industry has changed in terms of technological advancement and engagement. It benefited greatly from technologies like artificial intelligence (AI), machine learning (ML), the internet of things (IoT), cloud computing (CC), blockchain technology (BCT), extended reality (AR/VR), and digital twins (DT). BIM has an excellent potential to be combined with the internet of things, which can lead to better infrastructure and increased facility utilization, according to Digital Built Britain, which represents the next phase of the digital construction revolution in the United Kingdom. A virtual model that replicates the current state of the real model is referred to as a 'Digital Twins', and this idea has been around for a while. This concept collects real-time data using sensors, which are enabled by technologies such as machine learning and artificial intelligence. BIM is the foundation for digital twins by acting as a digital data management platform. Despite concerns about how BIM can handle different types of semantic information, it demonstrates that BIM and digital twins can complement each other. However, digital twins still require a framework to operate with other technologies. Laser scanning also bridges the gap between as-is and as-built BIM, helping to connect the later stages of the lifecycle with the design phase.

Additionally, technologies like cloud computing have proven to improve collaboration in BIM. However, using the Internet to exchange data between multiple team members can pose serious security concerns. Moreover, interoperability also appears to be an impossible challenge for different design teams as they struggle to manage and distribute information effectively. Some CDE solutions, for instance, separate data into silos, making important managing issues like security and audit histories challenging. BIM has recognized security as of extreme importance. Blockchain technology has been introduced to the research community to address security issues related to BIM. However, much of the research in this domain is either conceptual, based on surveys, or merely a literature review. Therefore, the discussed technologies are important and worthy of further study.

It is necessary to create a cohesive environment where all these technologies can be brought together to maximize the benefits throughout the lifecycle of a project. BIM provides a foundation, and integrating emerging technologies offers a solid framework to develop upon it. However, the connection between these technologies remains poorly understood. Hence, there is a need to explore new ways to bridge these technologies for better decision-making. Furthermore, it was noted that the use of BIM is constrained by a lack of understanding of its capabilities, which further supports the need for conducting this research to provide a thorough understanding of what BIM should resemble in the future.

1.5 Research Objective

The technological rigidity that characterizes the Architecture, Engineering, Construction, and Facility Management (AEC/FM) industry is the starting point for this academic work. Although BIM as a methodology is the start of something new, it should not be regarded as the end. As architects, engineers, and others, we should be able to instill in our projects the desire to improve performance, profitability, and user experience while contributing to the UN’s sustainable development goal (SDG) of truly creating smart cities. (Allen, 2016) begins a discussion about the future of the industry in the next decade or so in his Autodesk University conference titled “*The future of BIM will not be BIM - and it's coming faster than you think*”.

Overall, it can be concluded that there is a need for Building Information Modeling/Management (BIM) to adapt, develop, and mature through connections with other scientific disciplines. Although we frequently discuss the data, or more commonly information, however, we are unable to use it effectively. As a result, we continue to lose business value, from the design to construction and operation. The growing use of emerging technologies, together with BIM, is helping to solve many construction-related issues; however, the lack of connection between them results in the loss of valuable information. Therefore, despite the availability of the data, even years after BIM integration, there is still a need to fix inconsistent data utilization.

To fully embrace connected construction, which is one of the main goals of Construction 4.0, it is believed that the AEC/FM professionals should explore new ways of designing, communicating, and collaborating. Therefore, the main objective of this research is to investigate and identify the potential applications of the metaverse, with an aim to improve BIM processes for design, information management and collaboration. Metaverse allows the possibility to converge emerging technologies onto a single platform. Hence, this study discusses the significance of metaverse and its use cases in various industries, particularly in the AEC/FM sector. In the following chapters, the readers will be able to understand the potential benefits of the metaverse and the impact of their use in the construction industry.

2 LITERATURE REVIEW

2.1 Introduction to Web 3.0

The arrival of COVID-19 introduced remote working, which significantly accelerated the process of digital transformation. Key technologies, including blockchain, cloud computing, extended reality, and artificial intelligence, have experienced a dramatic increase in their use because of this new development. These technologies are serving as the foundation for the evolution of the internet. Web 3.0 is the third generation of the internet, which integrates data in a decentralized manner to provide a quicker, more secure, and customized user experience. The metaverse, a virtual environment in which we are all expected to interact in the future, is likewise built on Web 3.0 or Spatial Web. The term ‘Spatial Web’ is inspired by the shifting of information away from the screen and into the virtual space, providing end users with a unique interactive experience. **Figure 4** provides an overview of various layers for the understanding of the spatial web and explains the transition of information from the physical to the interaction layer.

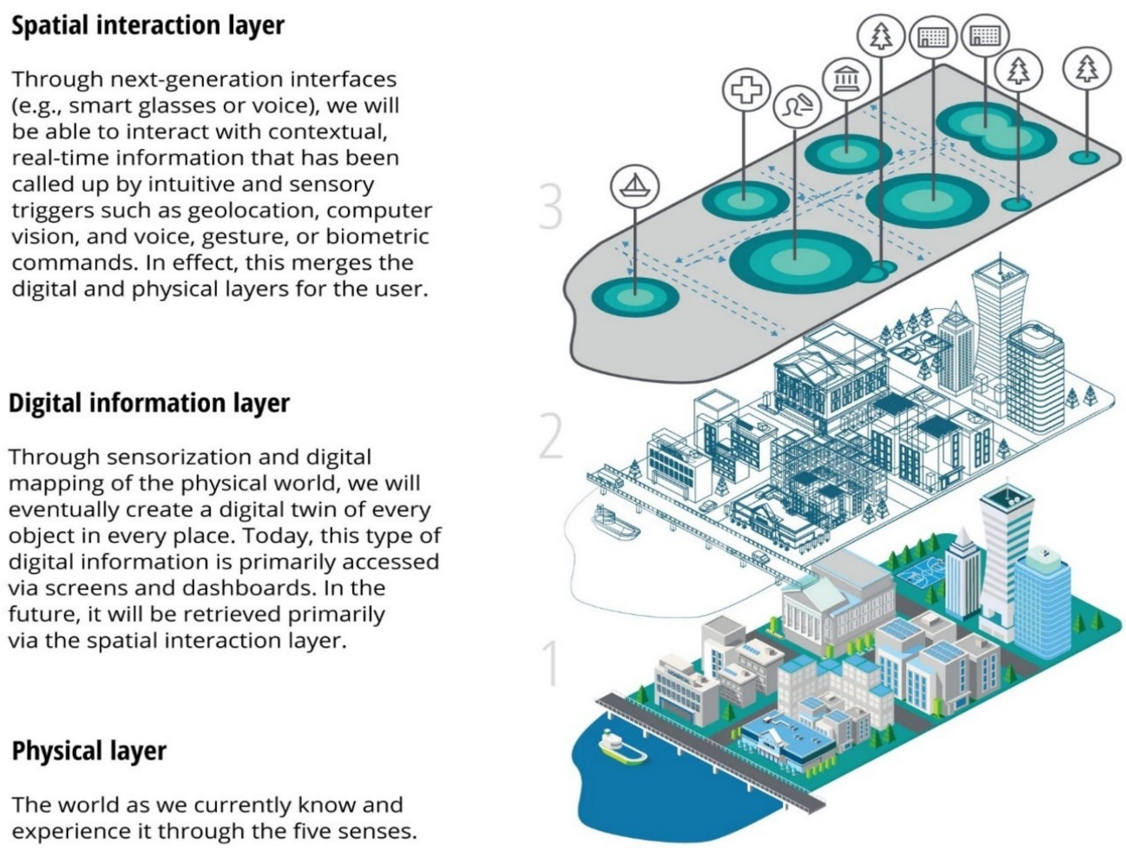


Figure 4: Understanding the Spatial Web - Source: (v. Cook et al., 2020)

To get a clear understanding of what the spatial web is about, it is important to step back in the past. In the 1970s and 1980s, the only ways to access the internet were using text-based interfaces, UNIX shells, and consoles. The world wide web was developed in the 1990s, opening the internet to millions of people by offering a more user-friendly interface that combines text and images to create two-dimensional worlds called web pages. This version of the internet is usually referred to as the first generation or Web 1.0.

In Web 1.0, users could browse and explore information using interconnected computers and servers. A centralized company, such as Yahoo or Google, typically provides this platform. Web 2.0 appeared as a dominant online platform in the early 1990s and is characterized by social networking sites, blogging, and the commercial monetization of user data. Web 3.0, the next generation of the internet, is distinguished by decentralization, transparency, distributed ownership, and increased user control. These pillars are underpinned by one crucial piece of technology, which is blockchain. In other words, blockchain has enabled Web 3.0 to develop into a digital marketplace in which users determine the worth of their product and control transactions and data.

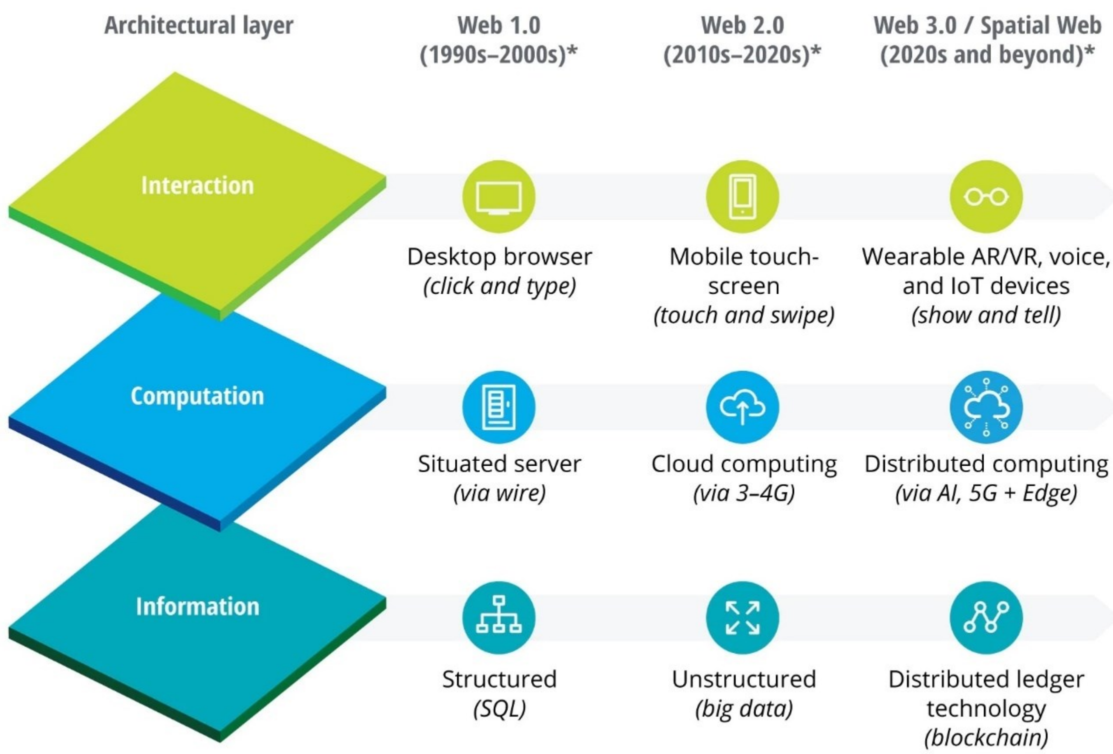


Figure 5: Three tiers of IT infrastructure and building the Spatial Web - Source: (v. Cook et al., 2020)

Web 3.0 is still evolving with the convergence of key technologies and the innovative approaches that fuel up and connect the IT infrastructure. **Figure 5** illustrates how fundamental enabling technologies power their respective computing era. Moreover, to fully realize the potential of the Spatial Web, improvements in all three levels of computing infrastructure are required. The three general stages of maturity are augmentation, optimization, and unification, as represented in **figure 6**. Many businesses are already producing value out of the augmentation and optimization stages; however, the unification stage is still predicted to be a few years away.

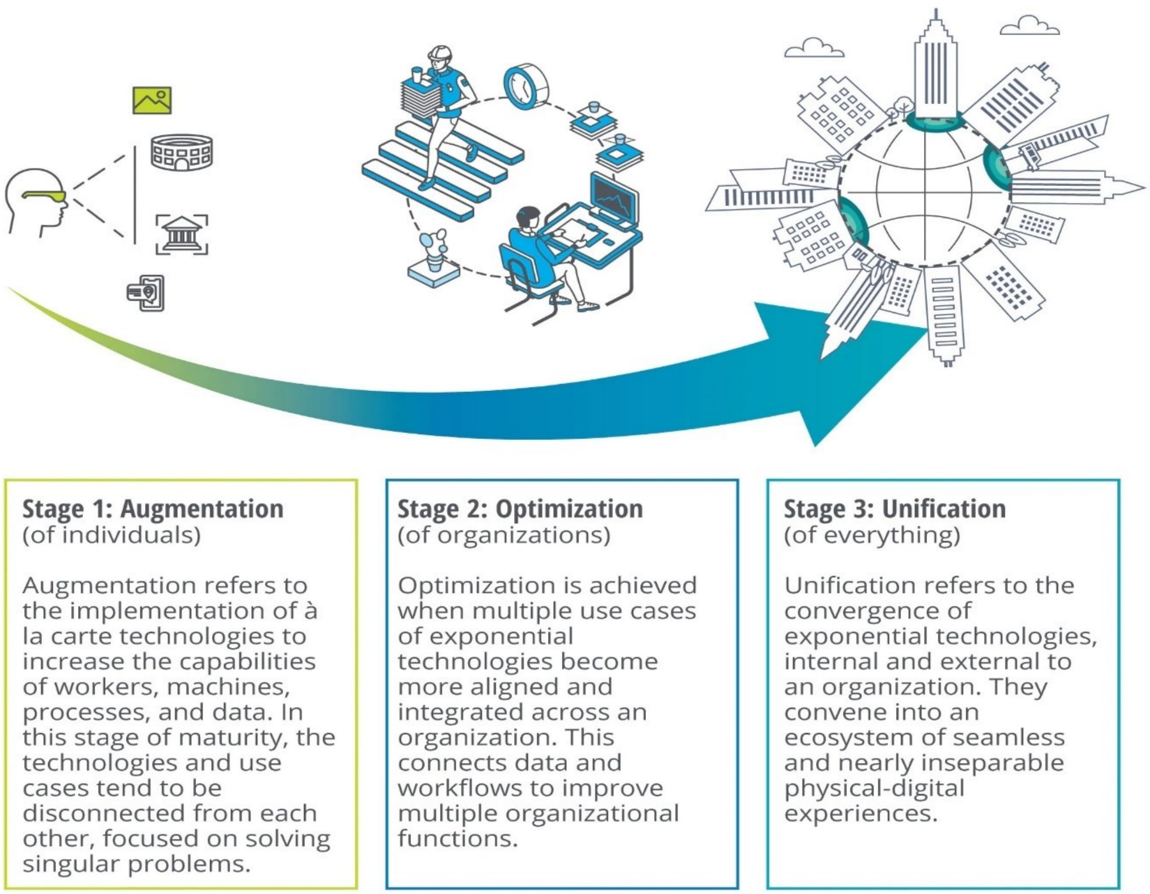


Figure 6: The path to the maturity of a Spatial Web - Source: (v. Cook et al., 2020)

2.2 Construction 4.0 - An overview

Industry 4.0 is based on the notion of the digital revolution, whose primary goal is to connect people and technology. Construction is one of the many disciplines that are involved in the process of a digital revolution. It can be defined as applying information technology to manufacturing, fabrication, and other industry-related processes (Alaloul *et al.*, 2020). Despite the apparent advantages of digitization, the construction sector is still lagging in adopting the Industrial Revolution 4.0 (IR 4.0). Based on the IR 4.0 concept, the technologies used in the construction sector have varying degrees of maturity. For example, BIM, Cloud Computing, and Modularization have advanced significantly while other technologies like Extended Reality (AR/VR/MR), Blockchain and Digital Twins are still being improved and potentially impact the industry's sustainability (Alaloul *et al.*, 2020).

Construction 4.0, a sub-domain of Industry 4.0, takes advantage of the developments and overarching ideas of IR 4.0 in the construction sector (Forcael *et al.*, 2020). Although researchers began combining the terms ‘Construction 4.0’ and ‘Industry 4.0’, Berger, in 2014, was the first to coin the term ‘Construction 4.0’, which has since grown in popularity (Forcael *et al.*, 2020). Despite the lack of a single definition, Construction 4.0 is widely recognized as a digital model driven by BIM and Common Data Environment (CDE) with the application of Data Science and IoT techniques. The primary areas of interest in Construction 4.0 are people, processes and practices, and new technologies. Some of the important transformational trends that can be used to broadly identify Construction 4.0 are Industrial production and on-site construction (includes digital fabrication, 3D printing, automation of manufacturing, and assembly); cyber-physical systems (includes robotics and automated production used on construction sites); and digital technologies (includes integration with AI, Big Data, Cloud Computing, laser scanning, Data Science, Blockchain, extended reality, and other data and computation-related technologies) (Sawhney *et al.*, 2020). This study primarily focuses on the third part and will discuss the emerging technologies facilitating the construction processes.

Figure 7 illustrates three layers of the Construction 4.0 framework based on the literature review (Sawhney *et al.*, 2020). BIM, CDE, and Digital Twins technologies make up the digital layer; BIM is a key component for providing modelling and simulation features, and CDE manages information flow and repository (Sawhney *et al.*, 2020). The physical layer contains the elements that speed up and digitalize construction site operations. The middle layer, known as the ‘digital tools layer’, communicates with the top and bottom layers. It primarily consists of technological tools that can be applied to the construction industry's digitalization, including artificial intelligence, big data, extended reality, blockchain, and other tools. The advantages of implementing the Construction 4.0 framework can be summed up as reducing time, cost, and energy consumption and improving quality, security, and a collaborative environment with a focus on lifecycle assessment and end results.

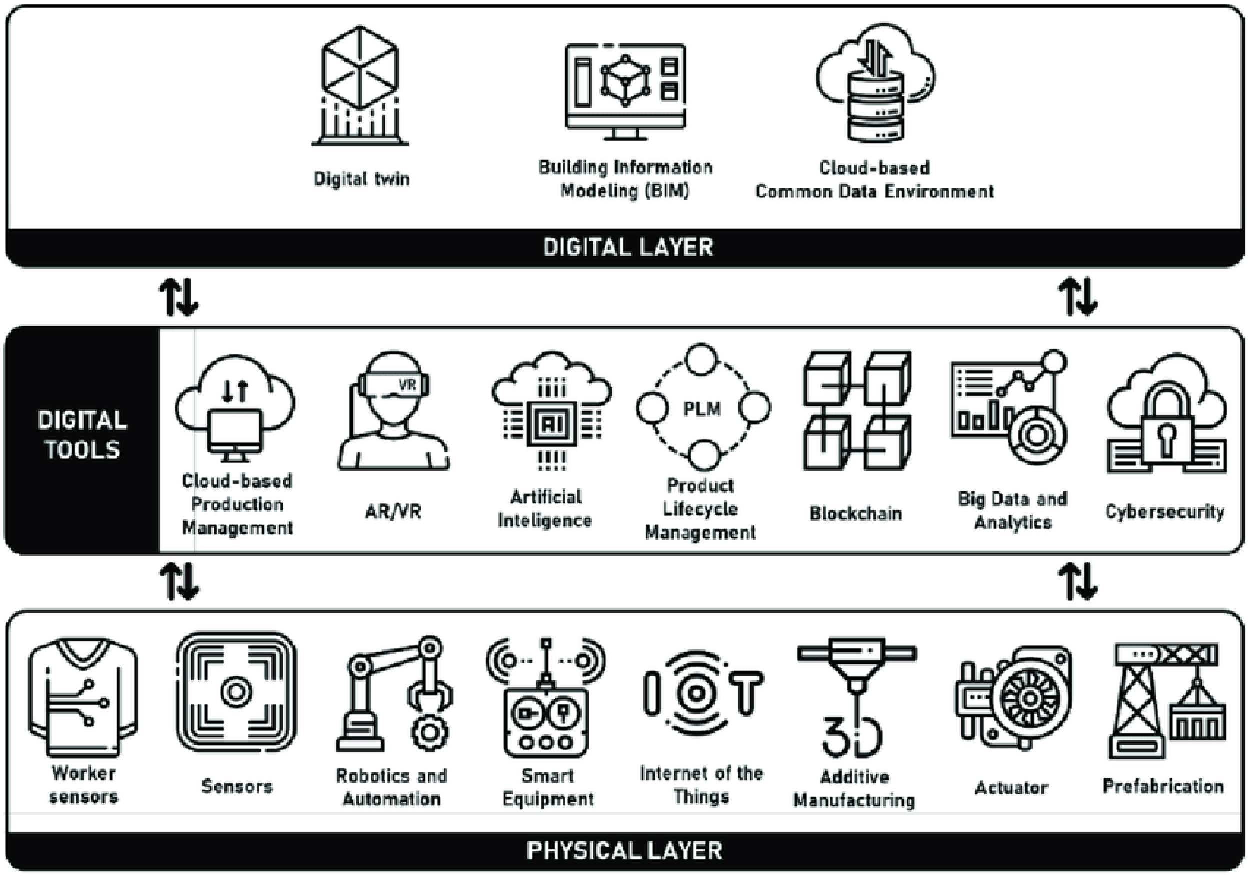


Figure 7: Construction 4.0 Framework - Source: (Sawhney et al., 2020)

Building Information Modeling (BIM), as defined by ISO 19650, is the value attained through improved specifications and identification of data requirements at the design, construction, operation, and maintenance stages of buildings and infrastructure. Therefore, it is crucial to mention that using the right technology is vital for delivering adequate information (Kemp *et al.*, 2019). In this chapter, we are going to discuss various emerging technologies and the impact of their use in the construction industry.

2.3 Technological developments to enhance construction processes

2.3.1 Cloud Computing

Cloud Computing (CC) refers to the distribution of computing services such as servers, storage, databases, networking, software, analytics, and intelligence over the Internet, as represented in **figure 8**. According to Microsoft Azure, it aims to provide faster innovation, flexible resources, and economies of scale. It allows users to break free from their preconceived assumptions about computing. With the ability to be used by many devices, including computers, tablets, and smartphones, cloud computing has emerged as a rapidly expanding technology that lowers the barrier to technological investment. It received the name 'cloud' due to its frequent representation in network patent diagrams from the early 1990s, giving rise to the term "Cloud Computing".

Although the term has been around for a while, it only gained popularity in 2007 when Google and IBM announced a collaboration in this field (Vouk, 2008). "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction", according to the US National Institute of Standards and Technology (Mell and Grance, 2011). The fundamental idea behind cloud computing is to consistently develop and operate network-connected computing assets to build a pool of computational resources capable of providing a user service suited to their requirements and expectations. Thus, a network that acts as a resource provider is referred to as a 'cloud server', and its resources can be expanded even further, made available whenever needed, and only charged for the actual use.

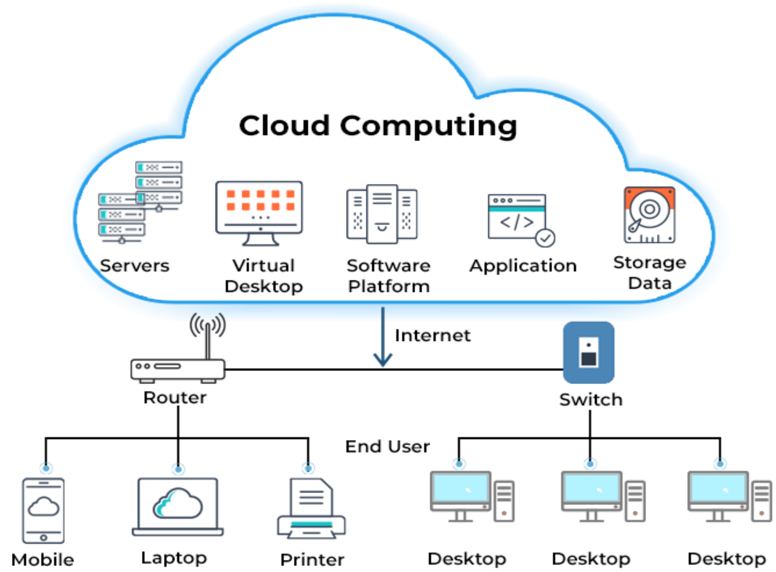


Figure 8: A general representation of cloud computing architecture - Source: (Patil and BasuMallick, 2022)

In the past few years, cloud technologies observed growing popularity in the construction industry. There has been a lot of research focusing on how to incorporate cloud components into BIM. Most of the studies have revealed that cloud-BIM can significantly impact the AEC/FM sector. Therefore, it is anticipated to trigger a new wave of change following the introduction of BIM (Wong *et al.*, 2014). Cloud-BIM development has facilitated information sharing, data storage, and real-time collaboration between numerous stakeholders. It also helps to manage and store BIM data by creating an environment that provides easy file management, quick access to BIM models and documents, and powerful computational capabilities

(Alreshidi, Mourshed and Rezgui, 2018). In addition, cloud-BIM allows decentralized storage of large BIM data, where information is encrypted, shredded into pieces, and stored in a global network of computers, offering a faster, cheaper, and more secure way of storing information. Cloud computing technology has emerged not only to solve collaboration issues, but it also encourages the use of web services for online visualization of BIM models (Lee *et al.*, 2016). BIMcloud, Trimble Connect, and Autodesk Construction Cloud are some major platforms offering their services in this domain. The benefits cloud-BIM offers to stakeholders throughout the project's lifecycle, along with easy access to data stored on a central server, are paving the way for BIM Level 3.

2.3.2 Internet of Things

The term 'Internet of Things (IoT)' refers to a network of things or objects with a unique identification or internet protocol address that can send data about the environment or the state and receive data associated with actions in actuators (Gbadamosi *et al.*, 2019). It is based on the notion of creating a web of interconnected devices like sensors, tags, GPS, cameras, and barcodes integrated into the internet in such a way that it offers access to the information in real-time. In addition, connecting the internet of things to the cloud allows for the creation of a network bonding for data transfer and system monitoring, where cloud computing can be used as a database to offer distributed storage, central server, and high-performance computing capability enabling real-time collaboration. Similarly, the information gathered from sensors may serve as input to technologies like artificial intelligence and machine learning. With the help of big data analytics, these technologies can turn this information into knowledge, enhancing decision-making (Begić and Galić, 2021).

The primary benefit of IoT in the AEC/FM industry is the availability of real-time data analytics. It facilitates performance monitoring, informed decision-making, and smarter designs, leading to increased productivity, lower emissions, reduced workforce, and quicker project delivery (Gbadamosi *et al.*, 2019). The combination of IoT and BIM provides a gateway for building real-time information models that can reflect the actual state of the project, connecting data coming from IoT devices directly to the Internet. However, (Tao and Song, 2019) reported that handling the enormous quantity of data created by sensors is extremely difficult, particularly when sharing this data between multiple stakeholders and systems. Moreover, technologies like artificial intelligence and machine learning can complement the internet of things to create a smart building. Machine learning performs well at occupancy prediction, safety measurements, material classification, and economical energy consumption (Begić and Galić, 2021). It also strengthens the concept of learning from past instances and improving, as repeating the same mistakes in a large project can be costly and time-consuming (Begić and Galić, 2021). In addition, when combined with

BIM, artificial intelligence can assist in planning and scheduling by enabling data-driven and intelligent automated decisions.

The success of the internet of things depends on linking data to building and monitoring it through artificial intelligence. For instance, the real-time information gathered from a construction site using IoT powers BIM to track the progress of a project (Begić and Galić, 2021). Moreover, an intriguing example of IoT is a construction site safety management system that detects real-time safety issues while storing data for future training and development (Begić and Galić, 2021). Furthermore, the internet of things can incorporate geolocation and environmental data into BIM (Begić and Galić, 2021). The uses of IoT outlined above demonstrate the diverse benefits it offers to the AEC/FM industry. However, as previously stated, the internet of things is a layered system that demands extensive collaboration to realize its full potential.

2.3.3 Extended Reality

Extended Reality is a general term that describes the spectrum of immersive technologies. It allows users to experience visuals, audio, and touch in an immersive environment when interacting between the physical and virtual worlds. Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) are three primary forms of Extended Reality (XR). The gaming and entertainment sectors benefit most from the extended reality. However, if used in the AEC/FM industry, these immersive technologies can boost productivity and efficiency during various construction processes.

The use of extended reality is still limited in AEC/FM, even though there is a strong consensus that this technology can completely transform this industry. Therefore, the potential of XR must be constantly unlocked and promoted. BIM has introduced new ways of working in the construction sector; however, if implemented in combination with cutting-edge technologies like XR, it can enhance the design and construction processes.

VR-integrated BIM is primarily utilized to support design, decision-making, construction-related education and training, and the management of construction safety. The construction sector, particularly facility management, has been significantly impacted by augmented reality. AR proved useful in reducing labour costs and reworks, enhancing safety, and ensuring timely maintenance. Moreover, mixed reality has been developed to help with design and construction education, support fabrication processes, improve cooperation between the teams, assist in decision-making, and encourage sustainability assessment (Alizadehsalehi, Hadavi and Huang, 2020). **Figure 9** presents some of the applications of extended realities in design and construction as reported by previous studies. In recent years, many research articles have been published describing the potential benefits of these immersive technologies in the AEC/FM industry. In addition, many construction businesses recognized the importance of extended reality; therefore, significant investment trends have been observed in XR integrated BIM.

n	VR	AR	MR	Integrated With BIM	Applications	Stage		Evaluation methodologies				
						D	C	R	F	S	CS	I
1	√			*	Monitoring of construction projects		√		*		*	
2			√	*	Applications of MR in the AECO industry	√	√	*				
3			√	*	Integration of BIM, lean construction, and MR	√	√	*	*			
4	√			*	Design and construction education	√	√			*		
5	√	√		*	Construction safety	√	√	*				
6	√			*	Collaborative decision making	√	√				*	
7	√				Construction safety	√						*
8	√			*	Construction safety training	√					*	
9			√	*	Prefabrication	√	√			*		
10			√		Construction safety-communication		√			*		
11			√	*	Site survey		√				*	
12		√		*	Evaluate the effectiveness of BIM and AR	√	√			*		
13	√	√			Operation, maintenance, productivity, safety		√			*	*	
14	√	√		*	Review and comparison of VR and AR	√				*		
15	√			*	Collaborative decision making	√	√				*	
16	√			*	Construction safety	√	√				*	
17	√			*	Construction safety	√	√				*	
18	√				Improving the understanding of architectural 3D models	√				*		
19	√			*	Benefits and challenges for VR in construction industry	√					*	*
20	√			*	Construction safety training/jobsite management.	√	√				*	
21	√			*	Building energy performance gap	√	√				*	
22	√				Construction safety	√	√	*				
23	√				Environmental representation	√				*	*	
24	√	√	√	*	Architecture and environmental planning education	√	√	*				
25	√				Show the value of using virtual environments	√	√			*	*	
26	√				Construction engineering education	√				*	*	
27		√		*	Real-time communication and problem solving		√				*	
28	√				Construction safety training	√	√			*		
29			√		Remote design review/problem-solving	√				*		
30	√				Credibility and applicability of virtual reality	√	√				*	

Note: n = Reference number; D = Design, C = Construction; R = Review; F = Framework; S = Survey; CS = Case Study; I = Interview.

Figure 9: Applications of Extended Realities (XR) in Design and Construction - Source: (Alizadehsalehi, Hadavi and Huang, 2020)

One of the industry-leading tools for immersive design, review and collaboration is Prospect, which was recently acquired by Autodesk. The design and construction teams working with BIM-enabled information models can use Prospect to connect with various 3D applications in a virtual environment. It enables real-time collaboration while offering an opportunity to showcase design to the clients in an immersive environment.

2.3.4 Blockchain Technology

Blockchain technology (BCT) is essentially "… a distributed database of records or public ledger of all transactions or digital events that have been executed and shared among participating parties" as described by (Crosby *et al.*, 2016). Each transaction is recorded on a code block in the public ledger using encrypted data and is only approved when confirmed by the users of the system. Each block has the following information: transaction data, a timestamp, and a cryptographic hash of the previous block. Once a block of information is generated, it can never be changed without the consent of the other users in the chain.

Additionally, it is very easy to confirm who created a block, when it was created, and what changes are made to this block, if any.

Blockchain technology aspires to develop a system that is auto-monitoring, self-regulating, and cyber-resilient to ensure trust and transparency. Over the years, it has evolved from enabling digital transactions (BC 1.0) to introducing smart contracts (BC 2.0) and recently, enhanced transaction time, scalability, and ease of implementation (BC 3.0). It has several advantages, including improved transparency, increased efficiency, instant traceability, automated contract execution, and enhanced network security. Blockchain technology enables proof of ownership and proof of provenance while also reducing human errors.

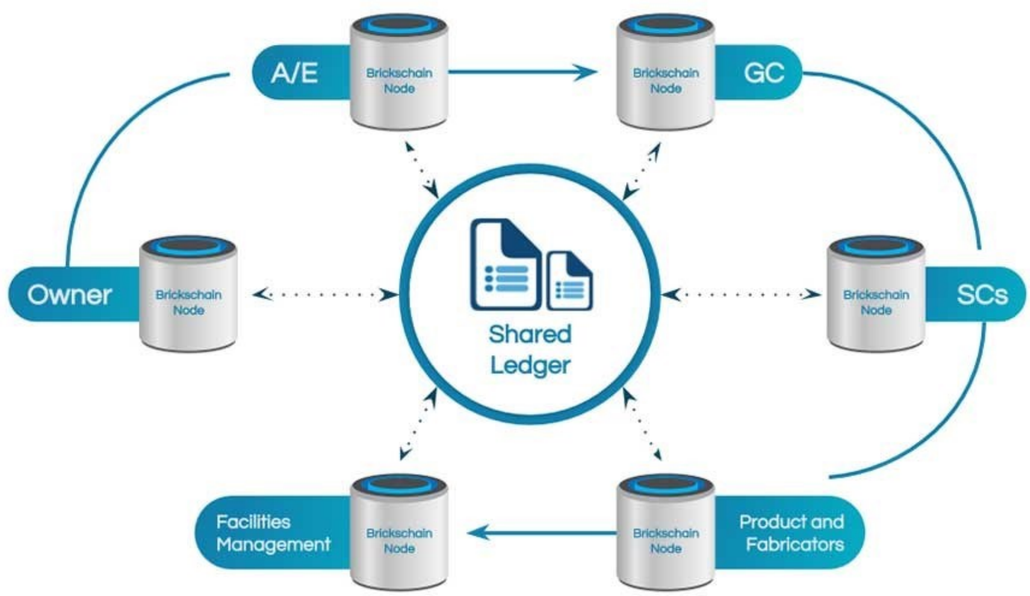


Figure 10: Distributed ledger system in AEC/FM - Source: (BRICKSCHAIN)

For the AEC/FM industry, blockchain technology offers benefits that are unmatched. The use of blockchain in the role of a shared ledger facilitates information synchronization between all the stakeholders, as represented in **figure 10**. Since BIM encourages collaboration, data exchange, and information management using cloud computing and the internet of things, it raises concerns involving data leakage, information security, and ownership rights (Siountri *et al.*, 2019). Therefore, given the complexity of the concerns, blockchain offers a unique solution to resolve these issues through the implementation of smart contracts. A smart contract is a computer protocol that defines the terms and conditions of a contract. With the help of smart contracts, contractual procedures that generally need human involvement and monitoring can be partially or entirely automated. For instance, it allows the contractor to get paid instantly when the job is finished after it has been validated by all stakeholders without the need for any invoicing procedure or third-party approval.

Moreover, any changes made in a BIM model can be routinely recorded on the blockchain, making it time-stamped, tamper-proof, and cryptographically secure. These changes can be accessed by all users of the blockchain, and the associated information can be approved or refused through a peer-to-peer network. This process gives more control over liabilities by ensuring traceability of the BIM data.

The BCT-BIM integration improves overall efficiency throughout the life cycle of a project. The provenance tracking ability of BCT helps to resolve authorship issues by recording data ownership within a shared model, eliminating unauthorized use of BIM data. It even allows the transfer of data ownership in exchange for payments in digital currencies. An example of these applications is the usBIM.blockchain, a platform developed by ACCA, which enables BIM data to be stored on the bitcoin blockchain, guaranteeing authenticity and immutability over time.

2.3.5 Digital Twins

The notion of the Digital Twins (DT) was first introduced by the aerospace industry, which later spread to industrial manufacturing (Deng, Menassa and Kamat, 2021). Recently, it has received a lot of attention in the field of the built environment. Digital twin technology is rapidly establishing itself as the foundation for developing a reliable information model expanding from BIM. Hence, a digital twin for AEC/FM is a dynamic but virtual copy of a physical asset or collection of assets that exhibits all features of a project to create insights throughout design, construction, and operation while enabling real-time data exchange between a built asset and its digital representation (Mercer, 2020).

A digital twin, unlike BIM or simulation, is not static. It evolves throughout the lifecycle of a project. In addition, it responds to input data coming from artificial intelligence, sensors, or the internet of things. Therefore, it can simulate actual building conditions and forecast future outcomes (Mercer, 2020). For some projects, a digital twin may simply have fundamental information, while for others, it can be completely developed with advanced simulations. However, the primary advantages remain the same. From the project inception to the facility management, digital twin lives and grows, providing new insights for increased return on investments, energy savings, performance, and maintenance (Mercer, 2020).

In order to get the maximum benefit during the design, construction and operation phase of a project, the knowledge of BIM can be used for the continued development of a digital twin. The foundation of BIM and digital twins is based on shared values; they both aim to increase process visibility, connect stakeholders, and assist them in planning. Moreover, they both are really helpful in assisting teams to view assets as projects in progress as opposed to isolated, capex-oriented investments (Mercer, 2020). At the start of the design or construction phase, effective BIM procedures and frameworks facilitate in establishing a clear vision for the project. However, once the work is started, there is a constant need to develop and enhance business value using real-time information. This is when digital twins come in handy. It uses real-time data to observe and manage assets, resources, and operational processes and, in response, improves performance and productivity (Mercer, 2020). In principle, a digital twin is an output of a BIM process, capable of evolving throughout the project lifecycle, as represented in **figure 11**.

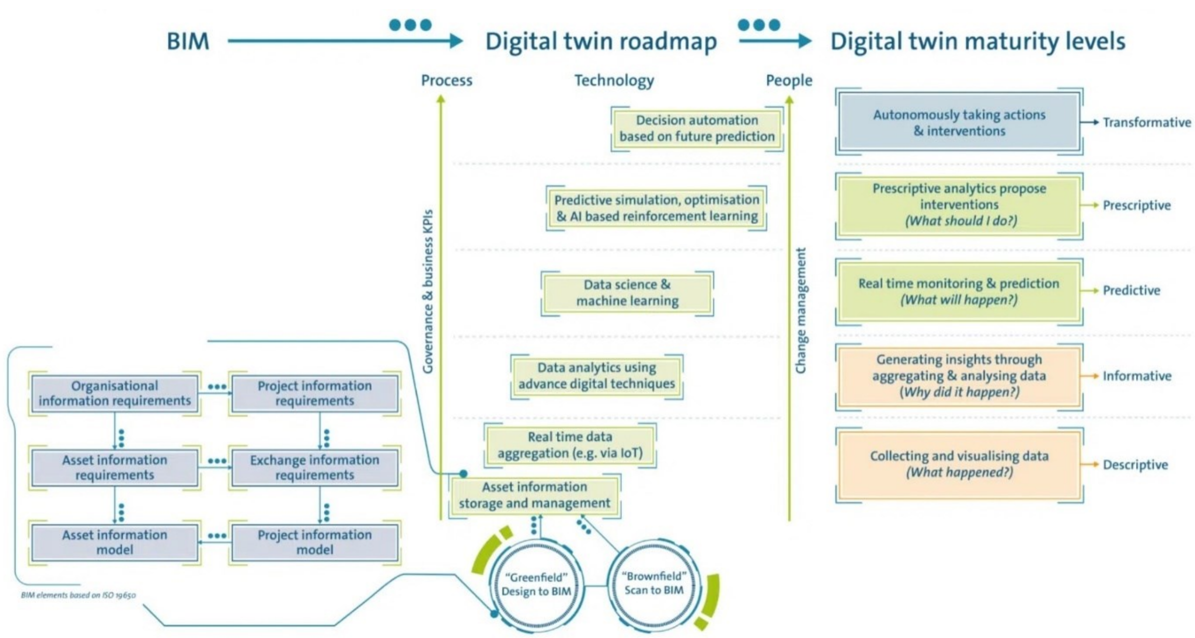


Figure 11: Information flow from BIM to Digital Twins - Source: (Mercer, 2020)

The digital twin serves as a single source of information throughout the lifecycle of a project. Once produced and implemented, it can be used to develop a self-learning system, optimizing maintenance plans and energy usage. It also eliminates the need for improvement teams to request input from construction teams. The dynamic data-driven nature of the digital twin provides access to real-time information and insights (Mercer, 2020). Therefore, making it possible to respond faster while ensuring low cost, hence, increasing the value of a project. However, for a dynamic data strategy to succeed, data issues must be understood and handled in the proper way, in accordance with BIM standards. There are enormous benefits of employing BIM methods to generate dynamic digital twins, ranging from better cost management to optimized performance throughout the lifecycle of a project. It guarantees that any updated or new data is kept

2.4 Future Developments

The world is changing, and all industries are under pressure to develop more resilient and creative operational models. As the standards of society are getting higher, customers/clients are becoming more and more demanding. Therefore, the challenges and opportunities are also appearing quite frequently. Due to these developments and the lightning-fast pace of technological advancements, nearly every industry is forced to undergo significant strategic adjustments and major business transformations (Mercer, 2020).

For AEC/FM industry, adopting BIM proved to be a crucial stride toward this transition. Many businesses have reported unprecedented uniformity and efficiency in their design, construction, and operation by adopting BIM methodology and standards (Mercer, 2020). BIM has demonstrated its importance as a tool for facilitating collaboration and information sharing among many stakeholders (Mercer, 2020). However, BIM alone is insufficient to modernize processes and resolve every single issue in the industry. It is a part of a process, and every process needs to evolve intelligently to achieve the desired outcomes. Hence, it is time to take advantage of BIM outputs and explore new avenues for expanding the usage of collaborative information models.

The emerging technologies, including blockchain, digital twins, augmented reality, extended reality, machine learning, the internet of things, cloud computing, and artificial intelligence, are all matured and have found their applications in the AEC/FM industry. There is no denying the fact that advancements in the aforementioned technologies assist in streamlining the procedures involved in design, construction, and operation. However, most of these developments are independent and do not connect. In the coming years, these technologies will converge, offering more scalability, and the sum in that convergence will be significantly higher than the parts. The metaverse, a 3D virtual space, may act as the catalyst for this convergence.

3 METAVERSE - HISTORY, OVERVIEW, AND EVOLUTION

The emerging metaverse is a three-dimensional spatial overlay of the internet. By blending the web interface with our interface to the physical world, it follows the trend of making the internet more intuitive and interactive for people. We can now begin creating such an interface, thanks to the convergence of the 3D computer graphics and simulation technologies developed over the past few years in CAD/CAM, AR/VR, and video games (VT-Lab, 2021). These developments have enabled users to live in an online virtual world using 3D holographic avatars. In other words, the metaverse can be referred to as the 'Internet of 3D'. Over the past few decades, the concept of the metaverse has been mentioned in many science-fiction and futuristic movies. Recently, the paradigm has undergone a significant shift that has caused this idea to call into question not only how we see the world but also the way we interact with it. Therefore, it is critical to pay attention to the changes that will result from the arrival of the metaverse.

Neal Stephenson, in 1992, first coined the term 'Metaverse' to refer to a virtual world that was widely used in his dystopian vision of the future in his book 'Snow Crash' (Welsh, 2022). In the book, users with VR headsets resided in a virtual space using 3D avatars of their choice. This virtual space is portrayed as a planet-encircling market where virtual properties can be traded. Without a doubt, this version of the metaverse is already available in the form of video games (Welsh, 2022). However, there is another way to describe the metaverse that goes beyond the virtual worlds. This description does not define the metaverse but explains why everyone believes it to be so significant. The explanation has nothing to do with a futuristic outlook or cutting-edge technology. Instead, it assumes that the metaverse must be created to supersede both the outdated technologies of the past and the existing state of the global internet and smartphones.

The metaverse is described as "*a successor to the mobile internet*" by famous venture capitalist Matthew Ball, who has written substantially on the subject. In the past, the invention of smartphones and the internet transformed technology, economy, and society; similar is predicted from the metaverse as well. Therefore, many businesses are racing to get ahead of it. The most challenging aspect of Ball's vision is his claim that the metaverse would be a single, open, linked, and interoperable network, as is the internet these days. This is a huge ask; however, the technology is being developed faster than ever and is well ahead of its time. Hence, it shouldn't come as a surprise if it happens in the near future.

The metaverse is a virtual environment that combines digital technologies involving videoconferencing, games such as Minecraft or Roblox, blockchain technology, virtual reality, social networking, and live streaming. It is unclear how these technologies will come together; however, some scientific geniuses already view it as the future of human interaction and collaboration. Mark Zuckerberg described the metaverse as "*the next frontier*" while rebranding 'Facebook' to 'Meta'. Moreover, the metaverse offers endless commercial prospects, which is one of the primary reasons why 'Microsoft' acquired game publisher 'Activision Blizzard'.

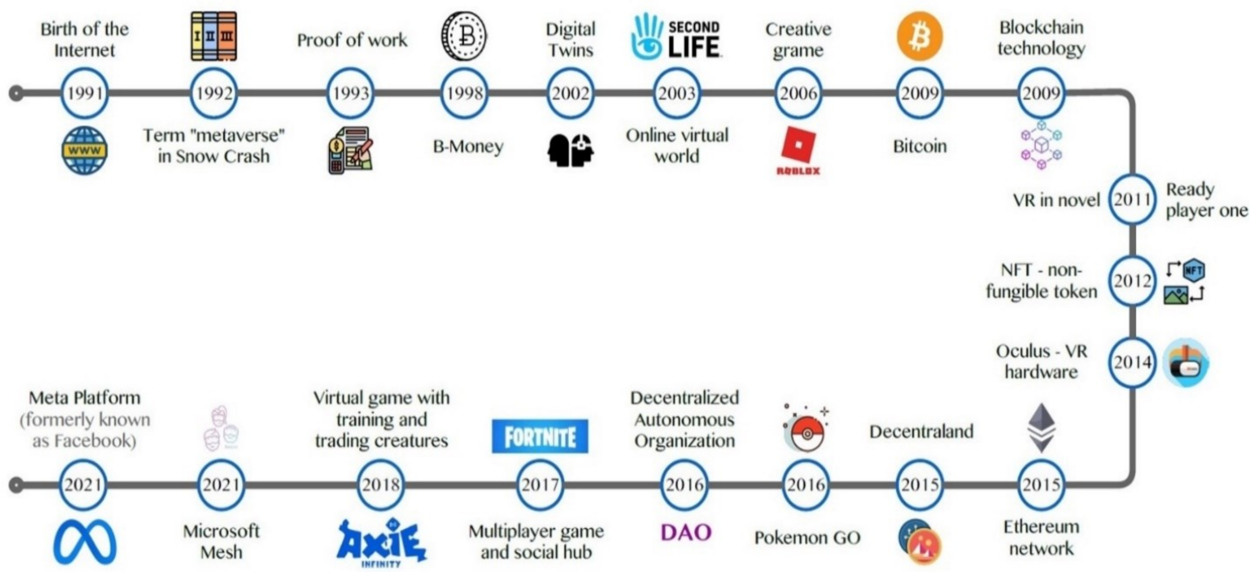


Figure 12: Evolution of Metaverse - Source: (Huynh-The et al., 2022)

The metaverse is not new; for decades, it has existed alongside the growth of the Internet and other emerging technologies. **Figure 12** above depicts the evolution of the metaverse concerning many major events ranging from the birth of the Internet to the latest developments in metaverse-related projects by prominent tech businesses such as Microsoft and Facebook. The metaverse is currently characterized as a digitally shared 3D environment, or perhaps, numerous cross-platform virtual spaces that offer users a fully immersive experience, including interaction and collaboration. In addition to fixed virtual spaces and structures in the virtual 3D environment, many other elements, including objects, user identities namely avatars, and digital products, may be traded across multiple virtual platforms using blockchain technology while also being mirrored into the physical world.

The metaverse, first and foremost, incorporates a social component. It is more than just a virtual place where people hang out alone or with a small group. Instead, the metaverse aims to connect the social structure that sustains human society. While in the metaverse, you can connect with others by making eye contact, perceiving body language, and possibly even shaking hands or hugging them. Second, it has a compelling narrative. Some believe that the metaverse is an entirely virtual environment accessible using VR headsets; an example is the game 'Fortnite' played with VR glasses. While others consider it as having a solid physical base connected with a digital interface that can be seen through augmented reality or perhaps more engaging mixed reality; an example is a game 'Pokémon Go' played on a mobile phone or using AR glasses. In any case, it helps to enhance our social experience by offering augmented virtual interactions. These 3D extended reality devices offer access to the metaverse and enriched engagement through current 2D screens employing WebXR technology. Third, it is being accelerated by emerging technologies such as web 3.0, blockchain, NFT, BIM, digital twins, artificial intelligence, and extended reality. It is critical to recognize that while metaverse might function without many of these technologies, the adoption and scalability would be severely hindered. Therefore, integrating BIM with these technologies makes it possible to set up a solid foundation for a secure, scalable, and realistic virtual environment in the metaverse.

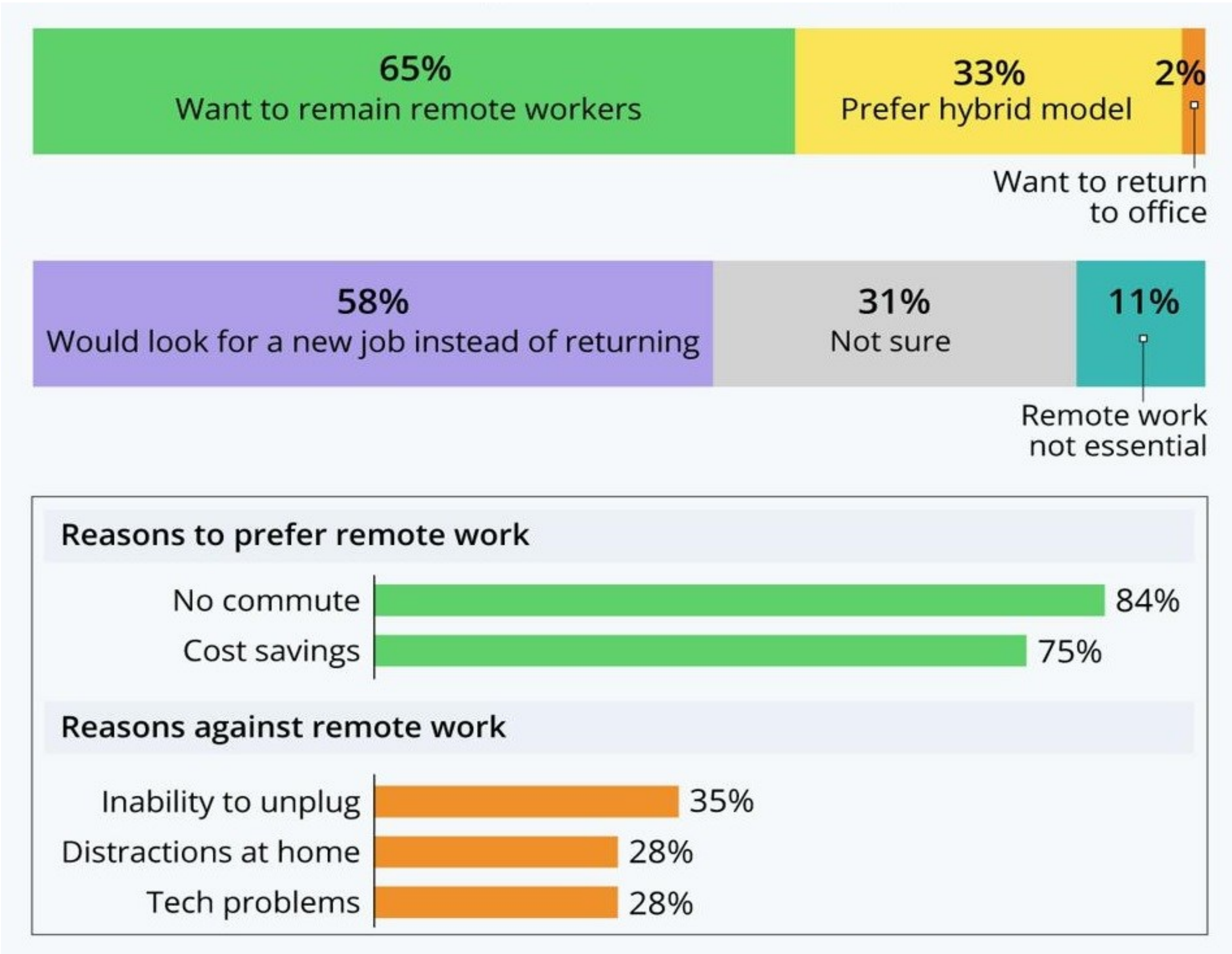
3.1 Why should the metaverse be explored?

3.1.1 Working remotely - A new normal

The post COVID-19 era has brought significant changes in the workplace environment. More and more employees are choosing to work remotely from home rather than returning to the office. According to the Tech Talent Outlook by employment site SCIKEY, the trend of working online was first imposed on employees owing to the pandemic, but after two years, remote working has become a new normal, and as things settled down, new habits have evolved.

Flexjobs has polled over 2100 employees who worked remotely throughout the epidemic and discovered that most of them desire to work remotely even after the pandemic has ended. According to Flexjobs research, an incredible 65 percent of the remote employees indicated that they intended to continue working online, and 58 percent even stated that if forced to return to the office, they would search for a new job. Merely 2% responded that they would like to return, while 11% claimed remote work was not necessary for them. The hybrid approach, a blend of office and remote work, was also popular, with one-third of respondents declaring it as their favourite working style.

The major benefits of working remotely, according to respondents, were not having to commute and the savings of travel cost, which were mentioned by 84 percent and 75 percent of remote employees, respectively. The inability to unplug (35%), distractions at home and technical problems (28% each), as well as getting a dependable WiFi (26%) and fatigue due to online meetings (24%), were among the reasons against remote work. **Graph 2** gives a brief statistical insight into how employees feel about the post-COVID remote work.



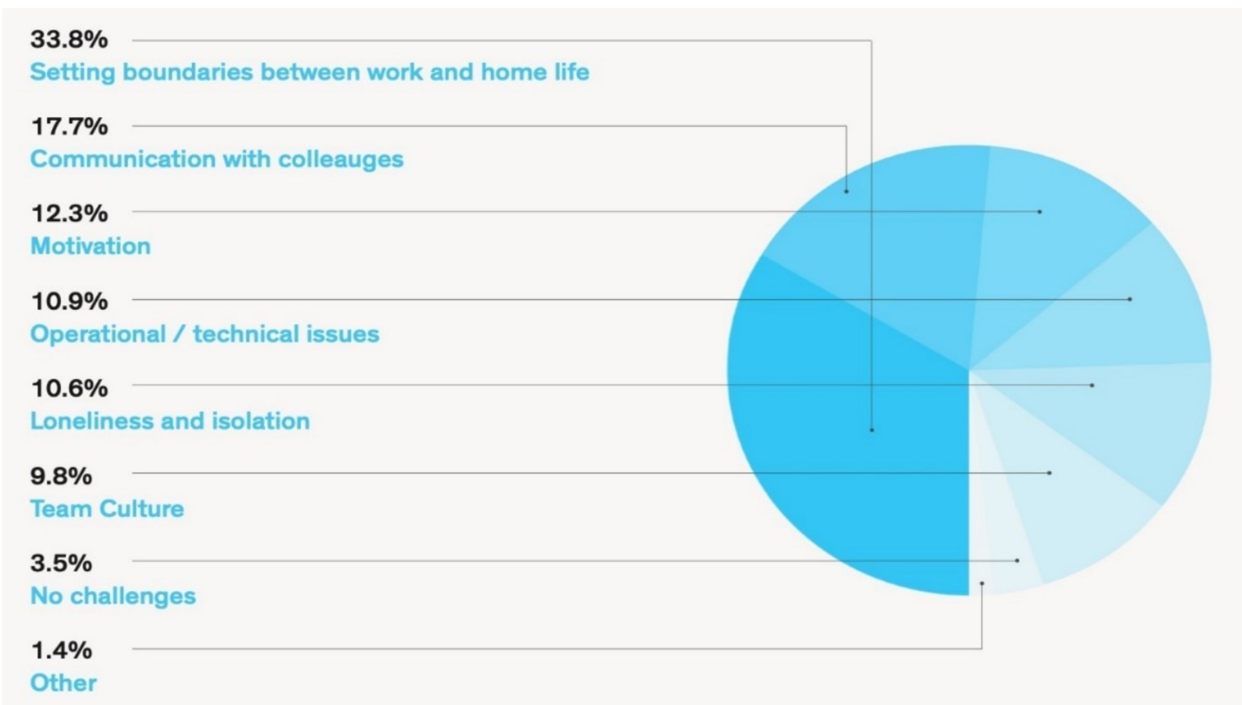
Graph 2: A post-COVID statistical insight on remote work - Source : (Flexjobs.com)

According to another survey, more than 80% of HR managers stated that employing people for a full-time physical position is becoming increasingly challenging. The technical workforce has discovered new love with remote work, offering them independence and productivity that demands HR to be more trusting. Working remotely is no longer an option; it is the new normal that every talented individual expects from the business, and the firms that are unable to adapt will encounter difficulties not only in attracting new talent but may end up losing those currently employed as well. Therefore, businesses should invest more in technological solutions to interact with their employees. This would help to achieve a deeper and more insightful engagement for the benefit of everyone.

Challenges and issues for AEC/FM professionals to work remotely

The construction projects are extremely complex in nature. This is due to the extensive ecosystem of designers, architects, engineers, builders, and subcontractors, all collaborating at various phases of a project lifecycle. However, the recent pandemic forced AEC/FM professionals to digitalize their operations, together with design processes and team collaboration happening online. Therefore, the implications of remote work have been most noticeable in architecture, engineering, construction, and facility management. As reported by AEC/FM professionals and represented in **graph 3**, the major challenges associated with working remotely are maintaining work-life balance, communication and collaboration with teams, lack of motivation, technological issues, and absence of social life.

In a study conducted by Architizer, it was reported that the COVID-19 had a significant impact on AEC/FM professionals. The study examined a range of problems, from design and communication to the psychological welfare of personnel, with an emphasis on connection to technology. The study revealed that nearly 80% of AEC/FM professionals worked remotely in 2020. According to the study, an astonishing 34% of the participants found it difficult to maintain a work-life balance. Around 33% said they missed team culture, felt isolated, and lacked motivation. While another 29% of the respondents reported that they faced technological issues when communicating and collaborating with teams during remote work.



Graph 3: Challenges and Issues for AEC/FM professionals with remote work - Source: (Architizer)

While COVID-19 pushed AEC/FM professionals to embrace new hardware and software for remote working, it has also prompted many practitioners to reevaluate their workflows. It is essential to reconsider the approach towards technology, moving focus to a remote collaborative environment where teams can stay productive and meet project targets. With the emergence of collaborative tools and immersive applications like metaverse, this shift can be facilitated to improve design, communication, and collaboration in AEC/FM industry.

What role can metaverse play in resolving these issues?

The construction industry has been slower than other sectors to adopt innovative technologies. This is because the design and construction teams are structured to work in silos. Moreover, construction businesses run on low-profit margins; therefore, many spend less on technology integration. However, the growing popularity of integrated project delivery has brought attention to the necessity of greater communication and enhanced information sharing among all project stakeholders. Furthermore, design and construction projects are intrinsically complicated. Since multiple organizations are working to create deliverables that are dynamic in nature, such as drawings, schedules, and budgets, even a minor oversight or wrong estimate can have a significant impact on the project.

Figure 13: Connected Construction in the Metaverse - Source: (bimengus)

The growing usage of BIM especially shared 3D models with information, is a great example of how the construction industry can embrace the use of technology to improve communication and connectivity.

Integrating emerging technologies like IoT, BCT, CC, XR and DT into BIM processes can help improve business value by solving various construction issues. However, the connection between these technologies is poorly understood. Therefore, it is required to create an immersive virtual workplace to converge these technologies, connecting important assets like 3D models, video conferences, real-time data visualization, facility management information, client feedback, transaction history and software applications, paving the way for a 'Connected Construction'. The term refers to the idea of having a unified technology platform to enable data integration among teams and stakeholders, as represented in **figure 13**. Using a connected strategy improves efficiency and lowers the possibility of error by providing real-time access to essential project data for all project stakeholders. According to a study conducted by McKinsey & Company, the investments in technology that coordinates design and construction doubled over the past few years. These investment trends, combined with the frustration of project teams and stakeholders when navigating through a sea of software applications, are raising the possibility of a potential technological revolution that will have a major impact on the construction industry.

The internet has seen astonishing technological breakthroughs in the last few decades, giving birth to the metaverse. Metaverse is an amazing 3D progression of the internet. There are many things that need to be defined in this virtual world; however, it has significant ramifications for how we interact, collaborate and work in the field of Architecture, Engineering, Construction and Facility Management (AEC/FM). In the future, AEC/FM industry will need to embrace working in the metaverse to meet the ever-changing demands of the client, intense competition, and ongoing talent pooling. Moreover, integrating augmented and virtual reality with the metaverse will be extremely useful in supporting the transition from traditional office-based work. It can significantly change the way things are done in the construction sector. By actively using the metaverse, the design and construction teams, together with clients, will be able to stay connected, at all times, from anywhere in the world. It will result in quicker approvals, fewer meetings, and less time wasted travelling, hence, speeding up the workflows. In addition, it allows tracking and resolving issues in real-time while staying connected to the team in a virtual 3D space. Metaverse offers more control to the clients by providing them with an opportunity to actively participate and give feedback throughout the design and construction process. It enables them to take decisions by virtually experiencing numerous options before they choose a final product, ending costly reworks and delayed construction.

3.1.2 Massive Economic Opportunity

A metaverse is a 3D virtual space which allows users to interact in an immersive environment. It has use cases extended to industries, including but not limited to gaming, healthcare, education, marketing, and real estate. In the last few years, an increasing trend has been recorded in the use of metaverse, mainly for working, socializing, and investing. A study conducted by PC magazine reported that approximately 52% of the global internet audience use metaverse in search of employment opportunities, followed by 48% for art and entertainment, 44% for financial investments, 40% for education, 32% for online socializing, and 29% for gaming. The study also reported that, in the near future, the metaverse is expected to produce job opportunities in various fields such as R&D, planning, digital assets, marketing, and cybersecurity.

The metaverse offers newer prospects for economic development. It counts on the latest technologies, including blockchain, cloud computing, extended reality, artificial intelligence, and digital twins, to enhance online education, gaming experience, and working remotely while increasing the use of cryptocurrencies and non-fungible tokens. The tech giants, including Facebook, Roblox, Nvidia and Microsoft, have already invested in the full-scale implementation of the metaverse. In 2022, the size of the global metaverse market was estimated at USD 47.48 billion, and it is expected to increase in value at a pace of 39.44% CAGR to reach USD 678.80 billion by 2030.

3.2 Layers of Metaverse

In order to better understand the metaverse, it is important to dive deep into its structure. According to Jon Radoff, CEO of Beamable, metaverse can be classified into seven different layers, as represented in **figure 14**. The following section introduces all these layers, namely, infrastructure, human interface, decentralization, spatial computing, creator economy, exploring, and experience. Understanding these layers is essential to define the conceptual segments that make up any metaverse. The technologies required to create the metaverse and the expected user experience connect these layers, corresponding to the value chain of the metaverse.

In creating the metaverse, the infrastructure layer incorporates the technologies that empower devices, allowing them to connect using an internet network such as 5G (Njoku *et al.*, 2022). The decentralization layer is powered by blockchain technology, which gives no control to any central authority, providing the foundation for a decentralized metaverse platform (Njoku *et al.*, 2022). The spatial computing layer aims to bridge the gap between the physical and virtual world by incorporating computing abilities in a remote setting (Njoku et al., 2022).

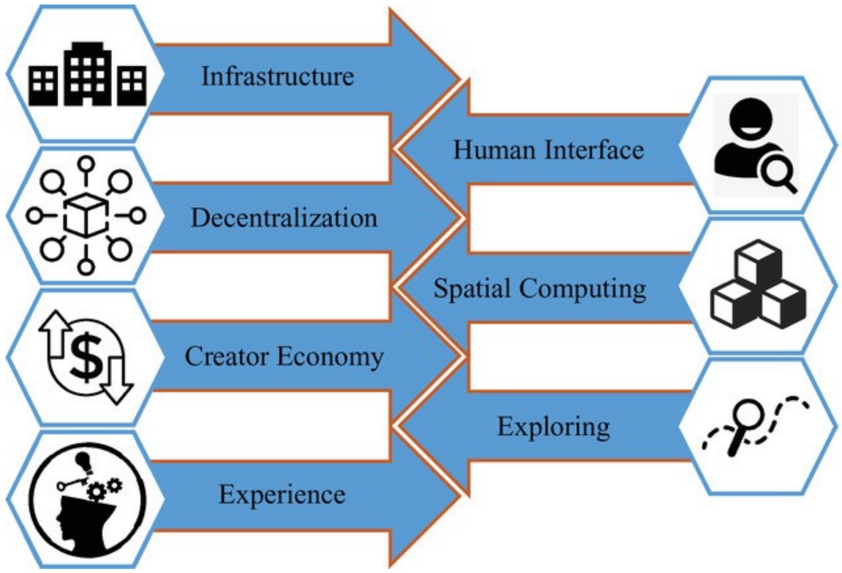


Figure 14: Seven layers of the metaverse - Source: (Njoku et al., 2022)

There is no use of the metaverse without any humans in it. Therefore, the human interface layer explores new ways to make it easier for users to access the metaverse. For instance, an application of AR/VR is a glove built using a human-machine interface that can identify motions in a virtual setting and offer feedback to the user. Hence, it is critical to have a human interface that is enabled by technologies such as augmented and virtual reality (Njoku *et al.*, 2022).

The layer that talks about the creator economy is the one that distinguishes metaverse from other virtual platforms. It encourages users to be creator in the platform, allowing them to develop assets in the form of non-fungible tokens (NFTs) and trade them for real money. Platforms like Roblox are already offering creator-driven metaverse experiences (Njoku *et al.*, 2022). Another crucial layer of the metaverse is the exploring layer, which revolves around the ability to explore and experience new things. It is divided into two broad categories, namely inbound and outbound systems. Users of the inbound system seek information such as community-driven content, search engines, and real-time presence. While in the outbound situation, the user receives unwanted information, similar to spam, pop-up alerts, and display advertising (Njoku *et al.*, 2022). The final layer, which is the centerpiece of the metaverse, is the experience layer. It incorporates all the new experiences in an immersive environment while blurring the boundary between physical and virtual space (Njoku *et al.*, 2022).

3.3 The current state of Metaverse

3.3.1 Decentraland

Decentraland is a 3D virtual world that can be accessed using a browser. This platform is based on the ideas of classic video games such as Sim City. It is one of the earliest and well-established platforms in the Metaverse. The platform uses MANA cryptocurrency for trading, a native ERC-20 token with a restricted quantity. MANA runs on the Ethereum blockchain, allowing users to purchase virtual plots and develop them by putting infrastructure in place. Decentraland has many layered components built using Ethereum smart contracts. The metaverse layer consists of a single grid evenly divided into plots using a coordinate system. Each plot is a non-fungible token (NFT) known as 'LAND.' Every time a LAND is purchased, the platform burns a portion of its MANA supply.

Figure 15: Importing 3D model to Decentraland - Source: (By Author)

Decentraland only supports .gltf/.glb file format, which offers better interoperability when importing asset information. This is because objects are mapped in hierarchical order minimizing the loss of information. **Figure 15** represents a workflow for moving the 3D information model from Revit to Decentraland. A 3D model created in Revit, if exported using .fbx file format, can be opened into Blender. Blender can convert this file format to .glft/.glf, which can be imported into Decentraland. However, multiple exchanges of file format can result in loss of information. Decentraland also offers the possibility to create a 3D asset using its own scene creator, ‘Builder’.

3.3.2 Cryptovoxels

Cryptovoxels is an Ethereum-backed blockchain metaverse. It is made up of a single metaverse layer that is unevenly divided into many islands called Parcels. Using magicavoxels, it is possible for owners to design, construct, and develop digital assets on their land. Cryptovoxels is compatible with the Oculus Quest, Oculus Rift, and HTC Vive and leverages babylon.js for high-performance rendering in the browser.

3.3.3 The Sandbox

The virtual realm of the Sandbox is very similar to Decentraland. It is a gaming platform that enables participants to freely design, construct assets, monetize NFTs, and interact with each other. This Ethereum-based blockchain metaverse underlines the importance of community members by encouraging them to be a creator of the virtual world. The whole in-game economy of this metaverse is supported by a native cryptocurrency called SAND. To make Sandbox a truly open crypto metaverse, the platform incorporates the usage of DAOs and NFTs. Think of it as a blockchain-based DeFi version of Minecraft. It enables the users to vote on the future of this project by utilizing DAO. Sandbox has assured the organic growth of the platform by putting the virtual world in the hands of its decentralized community.

To engage participants in the metaverse, Sandbox employs the play-to-earn technique. It allows users to collect digital goods that can be exchanged for real money in the NFT marketplace. The Sandbox users can also create NFTs using VoxEdit, a native feature of the platform, and use these NFTs to develop a game on their virtual land with the help of Game Maker. It gives users the flexibility to create and animate 3D projects within the metaverse. It has successfully bridged the blockchain and gaming industries, enabling both crypto natives and non-natives to create and sell their assets on this reliable and secure platform.

3.3.4 Somnium Space

Somnium Space is a free, open-source virtual reality world designed on the Ethereum blockchain. It allows users to buy property, build assets or import NFTs, play hyper-realistic video games, launch businesses, and hold live concerts or events. It is possible to enter the Somnium Space using any suitable device, including PC, VR headsets, or the web. The goal of this platform is to provide a unique experience to its users in an immersive virtual reality metaverse.

A true metaverse requires an independent, decentralized, and free-market economy. Somnium Space strives to make metaverse technology accessible to everyone with no entry barriers. The fact that it adopts a democratic financial approach and plans to develop its own blockchain-backed revenue-generating mechanism is significant. The Somnium Builder, a design tool by Somnium Space, allows users to carve their own place by creating a new property or importing a previously designed asset. To create an area in the Somnium Space, players must first acquire land parcels, which can be developed using Somnium Builder or NFTs and then explored in VR.

3.4 How does metaverse relate to BIM?

The notion of a 3D environment is central to the metaverse. It is essential for guaranteeing comfort to participants in the virtual world. For participants to feel the reality of the metaverse, a number of wearables have already been produced, such as VR headsets and haptic gloves. However, to fully embrace the metaverse, people need digital places to live, work or socialize in the virtual world, and they are willing to pay an incredible amount for these services. Therefore, architects and designers are essential to the metaverse. With the help of BIM, they can design spaces in the metaverse that were unimagined before. For instance, a famous architectural firm Zaha Hadid is designing futuristic buildings in their metaverse called Liberland.

Working with the metaverse demands acquiring new skills as well as a shift of perspective. Construction in the metaverse is anticipated to reach new heights as the younger generation of architects and engineers is well versed in both 3D modelling and digital technologies. Therefore, metacentric BIM (BIM in the metaverse) would enable them to design and interact with teams in a better way using gaming tools.

The metaverse is expected to reach billions of individuals in the coming few years. It has a good chance of developing into the next generation of social networking, streaming, designing, and gaming platform. In addition, there is a constant demand in the metaverse to create a realistic environment that resembles the actual world. With BIM, it is possible to create a realistic and detailed digital twin of any object or space. These digitally replicated objects or spaces can be integrated into the metaverse using 3D capture and virtualization technologies, magnifying the potential of this virtual world.

Many countries have already started investing in the metaverse. For instance, South Korea is going digital by creating a 3D replica of Seoul in the metaverse. It would enable tourists to visit historic landmarks using VR headsets, while the residents of the city would be able to meet city officials dressed as avatars. These developments will push designers, engineers, planners, and policymakers to consider future possibilities, such as contributing to the development of predictive models for analyzing climate change.

Figure 16: The user interface of various metaverse platforms; Sandbox (Top Left), Somnium Space (Top Right), Decentraland (Bottom Left), and Cryptovoxels (Bottom Right)

4 USE CASES, APPLICATIONS, AND BENEFITS OF THE METAVERSE

4.1 Use cases and application of metaverse in various industries

The internet is always evolving, simultaneously opening new doors to amazing opportunities. Everyone has experienced the power of digital evolution, from navigating through static webpages to interacting with web 2.0 technology. The next step in this progression is the metaverse. The idea of the metaverse has been around for a while; however, it only gained popularity in recent times. During the pandemic, people favoured online interaction, businesses embraced remote working, and digital communication became a new normal. However, face-to-face conversations, office settings, and in-person meetings still remained the preferred mode of interaction (Takyar, 2022). Metaverse offers the possibility to interact in an immersive virtual environment. Therefore, many businesses started exploring the potential applications or use cases of metaverse with an aim to implement it in their routine workflows.

The metaverse is a highly interactive 3D virtual world where users with customized digital avatars can explore and trade real estate, infrastructure, and other digital goods in the form of NFTs (Takyar, 2022). These avatars are digital copies of the user, equipped with all the human capabilities. With the help of virtual reality headsets, it is possible to augment this virtual world onto the physical space. In the future, the metaverse will become more engaging and realistic as a result of technological innovations, and users may be able to touch and feel virtual objects using haptic gloves(Takyar, 2022). In the following section, some of the existing and future use cases or applications of metaverse are discussed.

4.1.1 Enhanced Social Media Experience

These days, technology can do more than just facilitating human interaction using conventional social media applications. In recent times, social media has evolved from basic text chats to video conferencing and is now approaching the virtual realm of the metaverse. With the emergence of the metaverse, it is now possible to create a 3D virtual environment that goes beyond displaying people on mobile devices, computers or only hearing their voices (Takyar, 2022). A metaverse-based platform offers an immersive social media experience by enabling interactivity in a virtual space, taking online social interaction to a new level. In addition, the combination of augmented and virtual reality along with haptic gloves encourages an interactive online experience that goes beyond the capabilities of the current social media world (Takyar, 2022).

4.1.2 Immersive Sales & Marketing

The advancement in technology has introduced new prospects for e-commerce businesses. It enabled them to effectively market their services and goods. However, the arrival of the metaverse opened up an unparallel possibility for businesses to market and sell their products in an interactive 3D virtual environment (Takyar, 2022). Now, more businesses are moving away from the traditional 2D platforms into an immersive virtual world.

The metaverse allows e-commerce business owners to conduct trade formalities, including product inspection, negotiations, and transaction closure with merchants in a virtual setting (Takyar, 2022). In addition, it allows companies to attract customers by creating realistic products using interactive marketing strategies. The platform also supports innovative business ideas by encouraging the creation, ownership, exchange of digital products, and tokenization of physical products, empowering cryptocurrencies and NFTs (Takyar, 2022). Top brands like Nike and Adidas have already moved their businesses to the metaverse. Nike is introducing Nikeland, their own private metaverse built using Roblox, where they plan to market and sell digital copies of their products in the form of NFTs.

4.1.3 Revolutionized Remote Working and Online Education

The arrival of COVID-19 forced businesses to embrace digital communication (Takyar, 2022). The platforms like ZOOM, Microsoft Teams, and Google Meet observed a significant growth in popularity. These platforms offered the possibility of video conferencing, enabling online education and remote working. However, these platforms are unable to engage the audience due to the absence of dynamic interaction.

Metaverse can overcome this limitation by providing users with an opportunity to experience interactive 3D virtual space using immersive technologies like AR/VR (Takyar, 2022). It allows users to interact with other participants in real-time using digital avatars, rather than just watching them on a computer screen and speaking through microphones. More importantly, the metaverse has the potential to become a democratizing force in remote work and education, enabling global involvement on equal ground, unconstrained by geographical boundaries (Mystakidis, 2022). Facebook Horizon Workrooms, Microsoft SharePoint Spaces, and Synergy XR are some of the platforms that are offering virtual 3D spaces to enable immersive online education and remote working.

4.1.4 Advanced Blockchain Applications

Blockchain technology is necessary for the metaverse to be widely accepted across all key industries (Takyar, 2022). The cryptocurrencies like Bitcoin, Ether and Dogecoin are all powered by blockchain technology; however, BCT has the ability to do much more than simply supporting and maintaining cryptocurrencies. It facilitates the creation of digital assets in the form of non-fungible tokens or NFTs and the development of decentralized applications while serving as a distributed ledger for recording peer-to-peer transactions (Takyar, 2022).

With Metaverse, businesses can create NFT markets that are more engaging and interactive. It would enable customers to connect with businesses, view desired NFTs, and make smart purchasing decisions (Takyar, 2022). Moreover, the metaverse is pushing for advanced blockchain games created on platforms like Roblox or Minecraft, where players can create or buy in-game NFTs and trade them with other participants in exchange for real money (Takyar, 2022).

4.1.5 The Future of Entertainment

The metaverse represents the future of digital entertainment. In the metaverse, entertainment incorporates everything from online gaming or social networking to sporting events, concerts, or television shows. These activities are generally more engaging and interactive in the virtual setting than in the physical world, giving users a chance to have a more personalized experience. For instance, during a virtual concert in the metaverse, users have more control to be at any location of their choosing, with the possibility to even interact with the performer (Samsukha, 2022).

The users in the metaverse can communicate, interact, and watch games or events together. They can even purchase and dress the apparel of their loved teams, enter the playing field, meet their favourite athletes, and join the cheerleaders using multi-view camera technology (Samsukha, 2022). MLB baseball club, Atlanta, has already unveiled their official stadium in the metaverse and is prepared to host events. Moreover, the premier league football club, Manchester City, has recently made investments in developing its own metaverse. They are planning to create a digital replica of Etihad Stadium for fans to visit and watch matches in real-time from the comfort of their homes.

4.1.6 Realistic Online Gaming

The development of the metaverse is really essential for the next generation of play-to-earn games. Therefore, the gaming industry is significantly spending on R&D to explore innovative ways of delivering games to the metaverse (Samsukha, 2022). Moreover, the games that are based on the concept of the metaverse, like Fortnite, are gaining more popularity. This is because they provide an immersive and more realistic gaming experience to the players. In addition to playing these games, users can earn various in-game collectables in the form of NFTs and trade them with other participants or in any external marketplace (Samsukha, 2022).

The realistic content of metaverse-based games provides added value to businesses, with an opportunity to market their products to a larger audience (Samsukha, 2022). For instance, there is a clever way to advertise in the gaming metaverse, like showing ads at places such as in-game billboards or character apparel. Therefore, it allows businesses to create better visibility of their product in a gaming environment.

4.2 The potential benefits of metaverse to the AEC/FM industry

The concept of the metaverse revolves around design and collaboration; therefore, architects, engineers, and designers stand a chance to benefit most from it (Sadlock, 2022). The transition of the AEC/FM industry, from conventional office-based work to going virtual in a metaverse, is supported by extended reality. A simple zoom call cannot compare to the power of collaboration using extended reality. With the help of augmented and virtual reality, it is now possible to communicate with clients and showcase models remotely through fully immersive virtual presentations (Sadlock, 2022). Moreover, metaverse offers a shared virtual space to connect all essential components of the AEC/FM industry, including 3D models, collaboration, data visualization, project management, and web applications. For instance, the Wild and IrisVR offer the possibility to take a BIM model into a shared virtual space for immersive issue monitoring and collaboration using the latest VR headsets (Sadlock, 2022). Nvidia has also developed a scalable multi-GPU platform named ‘Omniverse’ for real-time simulation and 3D design collaboration (see **figure 17**).

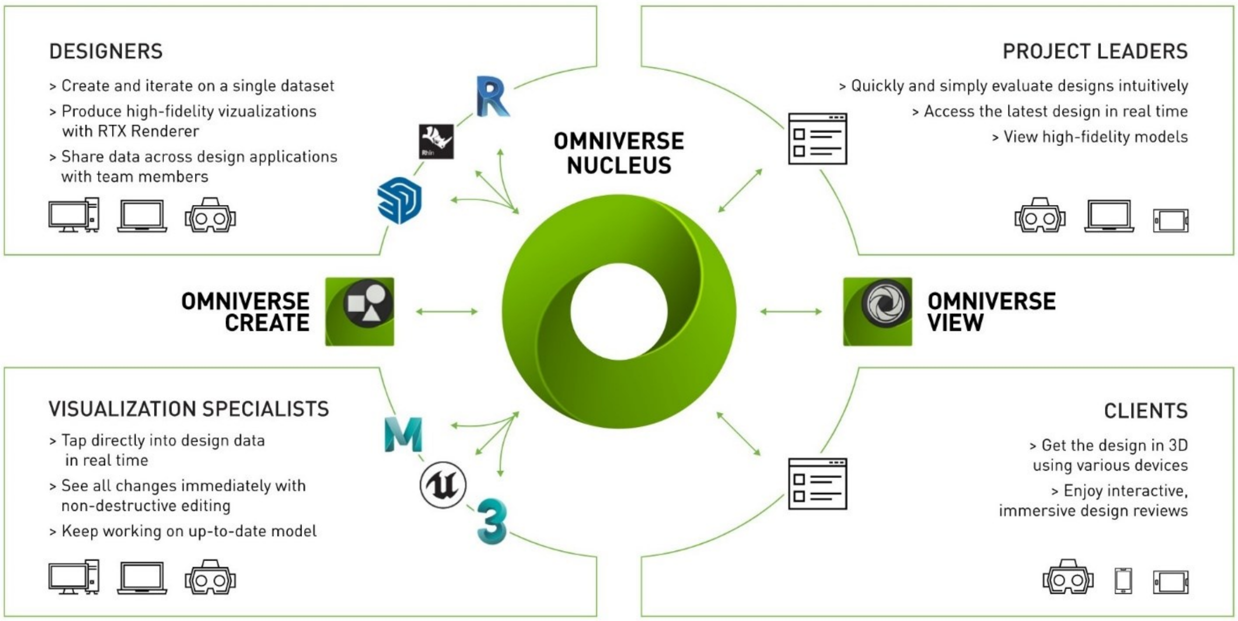


Figure 17: An overview of Nvidia Omniverse for design collaboration - Source: (Nvidia Omniverse)

The metaverse provides an opportunity for comprehensive life-cycle coordination, including the development of an asset information model, protected digital ownership, real-time collaboration, progress monitoring, immersive clash detection and resolution. BIM, an upgrade to conventional CAD, makes it easier to create a digital design for 3D model visualization without the need for investing time, resources, or materials to build a real or physical prototype (Sadlock, 2022). By bringing this model into the metaverse, it is possible to evaluate all possible solutions in a realistic environment before deciding on a final design option. It provides the flexibility to co-create design in a faster way, no matter if employing extended reality to test facades or fine-tune materials to meet clients' expectations. In addition, the metaverse allows all stakeholders to view, monitor, and control design in real-time, while ensuring that the end product meets their requirements (Sadlock, 2022). Therefore, it helps avoid the need for any costly rework, delays, or changes during the construction phase.

5 DISCUSSIONS

The metaverse has become a very hot topic of discussion these days. However, many people and businesses are still uncertain concerning the potential use of this technology. This research provided an overview of the metaverse and its potential use cases across various industries, with a special focus on the AEC/FM industry.

The metaverse can be thought of as a virtual world that can be experienced by people in a variety of ways, including an AR/VR headset, 2D screen on a desktop, tablet, or a smartphone. The study also discussed some emerging technologies and how they are paving the way to fully embrace the metaverse. Many of the elements of metaverse have been around for a while. For instance, Second Life was introduced in 2003, and caused a sensation in the gaming industry. It was the first platform that allowed the participants to remotely interact with each other in a virtual environment using their computers (Girroir, 2022).

This research highlights the importance of taking BIM processes into the metaverse, an approach introduced as metacentric BIM. Metacentric BIM enables efficient design, better collaboration, and facility management. **Figure 18** presents a potential framework concerning BIM processes in the metaverse. In the framework, it can be seen how emerging technology such as IoT, BCT, DT, CC and XR can facilitate BIM processes in the metaverse.

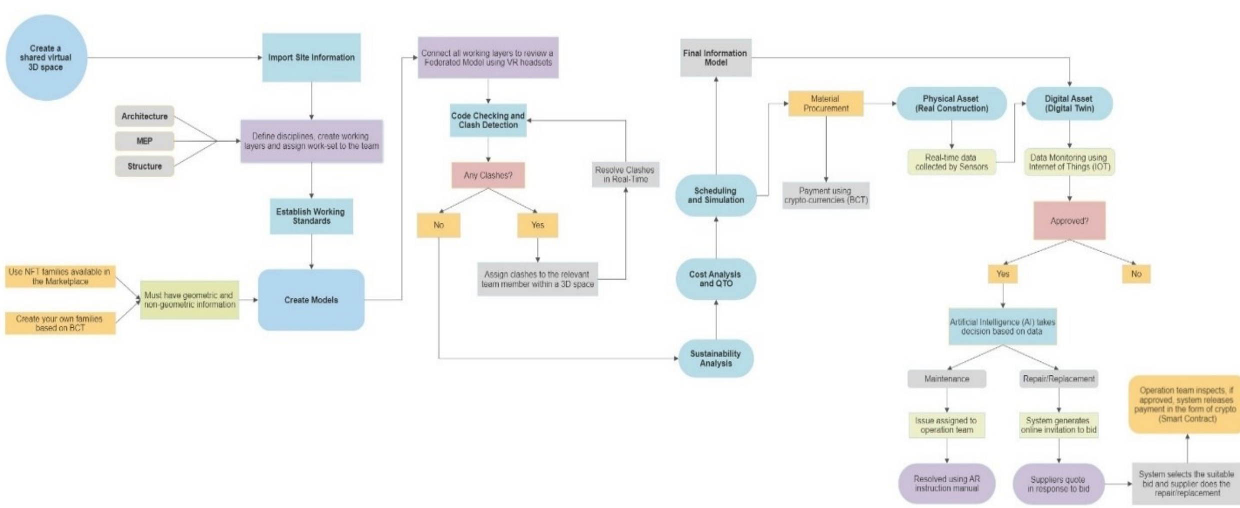


Figure 18: BIM processes in the Metaverse - Source: (By Author)

Metaverse can provide benefits at every stage of a construction project, from initial planning and design to construction and life cycle management. However, the primary challenge for construction software companies wishing to step into the metaverse is finding a common format for exchanging 3D BIM data in its actual form. Therefore, it is required to accommodate new data formats such as universal scene description or USD that enhance object quality by providing not only surfaces, geometry, and colors, but also roughness, shine, and environmental effects. The design workflow in the metaverse can only be made possible once that kind of support is put in place. In other words, the technology required to design 3D model in the metaverse is mostly available and all what is needed now is to put everything together.

Metaverse has the potential to become a go-to platform when it comes to designing a 3D information model. This is because of the visualization capabilities offered on the platform. Today, many well-known gaming platforms, such as Roblox and Fortnite, enable design in the virtual world powered by strong 3D engines (Girroir, 2022). These platforms allow users to create a 3D model much easier and faster using minted NFT objects. Using Roblox, it is possible to create a 3D model of an asset in just a few hours, which would nearly resemble the one created by BIM authoring software such as Autodesk Revit. The design of a 3D model on Revit and Roblox is not fully comparable as the latter may not contain all the information required for its construction and maintenance. However, what is astonishing is the ease with which this model can be created on this gaming platform with high visualization capabilities. In the coming years, with more developments in the metaverse, it may become possible to create an even better and more realistic 3D design or information model than conventional design applications.

In the AEC/FM industry, many companies in the past began offering Cave Automatic Virtual Environment or CAVES. It enabled the clients to have a virtual construction site experience without actually visiting it (Girroir, 2022). These days, virtual reality headsets can be used to create a similar experience. Platforms like IrisVR and the Wild can be used to collaborate in an immersive environment using a shared 3D space. Design teams can collectively work on 3D models in real-time to create an efficient model. Any clashes in the model can be detected, assigned to concerned team members, and resolved in real-time while viewing the model in an immersive space. The design changes during construction and operation can automatically be updated in the metaverse, giving more control over the information during the entire lifecycle of a project. To put it simply, collaboration in the metaverse can offer a wide range of advantages to the AEC/FM industry, provided that it is supported with the right tool and technology (Girroir, 2022). Therefore, as it evolves and becomes more mainstream, it would allow engineers and architects to design and collaborate across teams and time zones.

The maintenance, operation and management of a facility can be much simpler and easier if done in the metaverse. For instance, the sensors connected to the physical facility can share real-time data using IoT. The collected data can be compared to a digital twin in the metaverse to monitor any anomaly. If the system detects any issue, embedded artificial intelligence and machine learning algorithms can take data-driven decisions to initiate maintenance or repair/replacement procedures. In case of maintenance, an operation team equipped with AR/VR devices can be mobilized to resolve the issue. They can directly access the metaverse to see the instruction manual attached to the digital twin or ask for remote assistance. While in case of repair/replacement, the system can automatically generate the invitation to bid and publish it in the metaverse. All the suppliers or construction companies available in the metaverse can see and quote in response to this bid. After evaluating all the bids, the system can go into a smart contract with a suitable party. Once the repair/replacement is carried out, it verifies it again through the data coming from sensors and can release the payment in digital currency using blockchain technology. This way, the process can be automated by connecting all the technologies to a single metaverse platform. It ensures reliable decision-making and efficient human resource management while saving time and money.

6 CONCLUSIONS AND RECOMMENDATIONS

This study summarizes the potential applications of a metaverse in the AEC/FM industry. Although, this technology is still in its development phase and may require many years to be fully embraced by the construction industry. However, it has a huge potential to completely transform how things are done in the construction sector. This work can be an overview for any future research concerning metacentric BIM.

Mainly, there are two ways in which AEC/FM industry can benefit from the metaverse. The first one is based on interoperability, where a final BIM model created in any authoring software can find its way to the metaverse. This model can be minted as NFTs and then rented or sold in the digital world to generate revenue. However, the current challenge is to discover a suitable file format that can be used to transfer this information. For instance, Nvidia is working on a project called Omniverse, intending to create an interconnected network of the web. Their vision is to make it easier for users to move information around the metaverse using a single file format. They plan to use universal scene description or USD file format in their 3D ecosystem. Pixar developed this file format in 2012 to ensure a common language for defining, editing, collecting, and exchanging 3D information. But it is still too early to predict the future of interoperability in the metaverse.

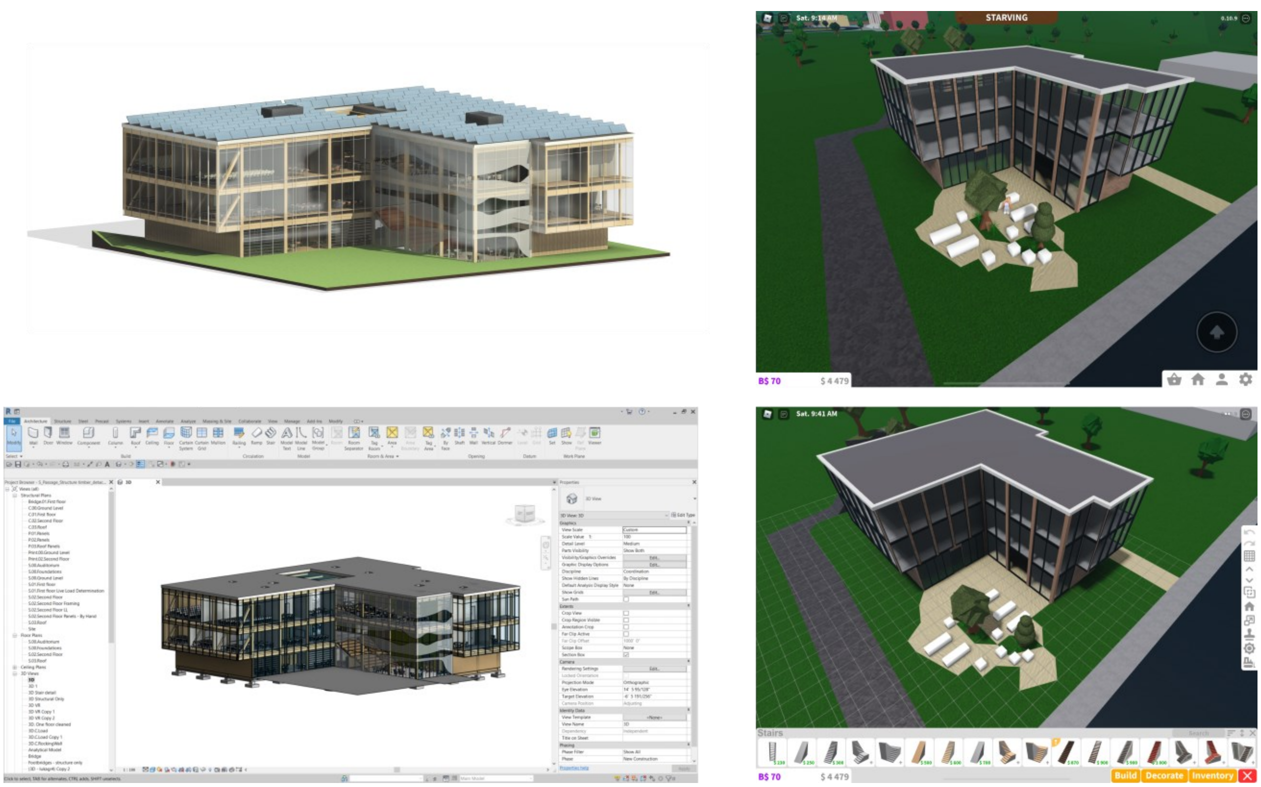


Figure 19: Revit model and editing environment (left) vs Roblox game and modelling environment (Right) - Source: (Revit model/screenshots By Luka Gradišar, Roblox model/screenshots by Erin Dolenc)

The other way is to develop a platform that can create a BIM model within a virtual space. It can be useful to connect various teams in an immersive setting. Some big companies like Autodesk are already investing in stepping into the metaverse. For instance, the Wild and IrisVR offer the opportunity to take the Revit model into a shared virtual space for coordination. Similarly, a gaming platform Roblox allows users to build in-game assets using NFT objects available on its marketplace. For now, the results may not look as realistic as they should (see **figure 19**). Still, it has got a huge potential to replace the conventional work processes in the AEC/FM industry altogether. There are a lot of pieces that are still missing on these platforms; therefore, these platforms would need more improvements to reach their full potential. However, soon, it is very likely to have a shared virtual space in the metaverse, where all the teams could connect easily using emerging technologies to design, collaborate, communicate, change, and manage construction projects in real-time.

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