Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 253 (2025) 155–166

Procedia Computer Science

www.elsevier.com/locate/procedia

6th International Conference on Industry 4.0 and Smart Manufacturing

Immersive representation exercise in BIM through the integration of prerequisites and requirements: structuring of an artefact applied to a case study

Simone Balin[a]*, Cecilia Maria Bolognesi[a], Paolo Borin[b]

[a]*Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, Italy*
[b]*Università degli Studi di Brescia, Piazza del Mercato 15, 25121 Brescia, Italy*

Abstract

This study explores the level of informational granularity required when immersive technologies are integrated into BIM for collaborative processes in public procurement. Despite advancements in immersive technologies and BIM, there is a significant gap in the standardization and structuring of information for immersive experiences in the AEC sector. Current standards and guidelines primarily focus on structuring and organizing data in a traditional digital environment, overlooking immersive aspects such as representation and interaction within immersive ecosystems. This creates a disparity in the effective use of BIM with immersive technologies. The concept of the Immersive Necessity Level was developed with the aim of addressing all the informational gaps required by immersive ecosystems, which are not currently met by the Informational Necessity Level defined by ISO 7817-1. Through three simulations, the study investigates how data specificity and informational granularity influence users' immersive experiences. The findings highlight the importance of defining clear prerequisites and requirements when outlining an informational framework using immersive technologies in conjunction with BIM methodology. This study aims to bridge this gap by proposing a structured framework to define the levels of immersive necessity in BIM projects. Furthermore, the research identifies challenges and potential improvements for future investigations, contributing to enhancing the standardization and effectiveness of the use of immersive technologies in the AEC sector.

* Corresponding author. Tel.: +39.02.2399.5122
E-mail address: simone.balin@polimi.it

1877-0509 © 2025 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 6th International Conference on Industry 4.0 and Smart Manufacturing
10.1016/j.procs.2025.01.079

Keywords: AEC industry; augmented reality; Building Information Modeling (BIM); collaborative process; Immersive Technology (ImT); virtual reality

1. Introduction

In recent years, the architecture, engineering, and construction (AEC) sector has undergone a significant transformation with the advent of immersive technologies and Building Information Modelling (BIM). These innovations are reshaping how professionals design, construct, and manage built environments. While the gaming industry supports the development of immersive content and immersive level requirements with specific programmes and standards that are well-defined and updated [1], the AEC sector still lacks standardised criteria and processes for the use of immersive technologies [2]. This gap is becoming increasingly relevant as more powerful and affordable tools become available [3]. The effective integration of immersive technologies with BIM methodology has the potential to redefine communication and collaboration both on-site and, in the office, [4], facilitating rapid evaluation of design and execution phases [5]. However, the absence of a standard for immersive representation and the management of BIM models in the AEC sector is evident. Previous research has highlighted this gap, leading to the formulation of the following research question: "How does the use of immersive technologies in collaborative processes with BIM methodology require specific information and/or data to be correctly applied?" [3]. Current standards focus on structuring and organising data and relationships in traditional digital environments, neglecting immersive representation, which inherently has different characteristics and information requirements [6]. This gap hinders the adoption and effective use of immersive technologies in BIM-based collaborative processes.

Our research aims to address this critical gap by exploring the level of information granularity required when immersive technologies are integrated into BIM for collaborative processes. We introduce the concept of the Level of Immersive Need, differentiating it from the current Level of Information Need as structured in ISO 7817-1 [7]. Through a series of simulations, we investigate how data specificity and information granularity influence users' immersive experiences. This study employs the Design Science Research Methodology (DSRM) [8] to structure an artefact that integrates prerequisites and requirements for immersive representation in BIM. Our goal is to provide a framework that allows for a clear definition of immersive needs in BIM projects, facilitating more effective implementation of immersive technologies in the AEC sector. By addressing these challenges, our research contributes to ongoing efforts to optimise design and construction processes through the integration of immersive technologies and BIM methodology. The document is structured as follows: Section 2 provides the background, discussing the informational needs in the AEC sector and distinguishing between informational and immersive needs. Section 3 describes the methodology, detailing the procedural framework for immersive programming, including the case study, prerequisites, requirements, and procurement procedures. Section 4 presents three experimental scenarios using the case study of the Borgo Pirelli neighborhood in Milan, demonstrating the application of the framework with various immersive tools. Section 5 discusses the results of the experiments and outlines potential future developments, including a timeline for further research. Section 6 concludes by summarizing the key findings and their implications for the integration of immersive technologies with BIM.

2. Background

2.1. Technical Knowledge and Information Needs in the AEC Sector

In the AEC sector, acquiring a solid foundation of technical knowledge is essential for successfully designing, constructing, and managing buildings and infrastructure [9]. Informational need refers to the collection of data, information, and knowledge necessary for making informed decisions in the AEC sector [10]. This may involve researching technical information, analyzing design documents, and consulting industry guidelines and standards. There is also a sensory and perceptual aspect, which utilizes sight, hearing, touch, and other senses, contributing to improving the final quality of the work along with the gathered information [11,12] This type of information cannot be adequately collected and addressed with the currently available requirements when using BIM methodology, as specifics such as the behavior, static or dynamic, of an object or model, the relationship between object and users, and the characteristics of information representation (visual, auditory, or multisensory) are not defined a priori [3]. This makes it very challenging to create an appropriate informational flow and choose the suitable equipment and tools for the purpose [13]. Throughout this, data forms the essential basis from which all subsequent considerations derive. From the information gleaned from data, knowledge is attained, the highest level achievable by machines, for example, through neural networks [14]. Subsequently, the concept of consciousness arises, an attribute exclusive to some living beings, defining information crucial for engagement based on the five senses [15], allowing for the experience of immersion or, more precisely, immersive consciousness [16]. While machines can provide advanced functionalities and engaging interactions, the notion of "immersive consciousness" typically remains limited to the human realm [17].

2.2. Distinguishing Information Need from Immersive Need

The Level of Informational Need can be labelled as the quantity and quality of information necessary to understand or address a specific situation or topic to meet the cognitive needs of the user or machine [10]. The level of immersive need, on the other hand, can be defined as the engaging experience that a person can undergo in a specific environment or situation. This sensory engagement implies partial or complete immersion in a virtual world or experience. Immersiveness is not directly translatable into information but concerns the representation and interactive experience of the user with such information [14]. This distinction could help reduce inertia in the adoption of immersive technologies in the AEC sector, expanding collaborative interactions and choices. In the context of BIM, the need for immersive level can be defined as the ability of a model to provide an engaging experience to users, in addition to informative knowledge [18,19]. This engagement can be achieved through the use of immersive technologies such as virtual reality and augmented reality, allowing users to explore and interact with the BIM model at various levels of immersion [19–21]. Therefore, the Level of Need should not only be informative and used to specify the structure, quantity, and quality of information, but in the case of virtual environments also immersive, defining how this information is represented and presented to the end user, structuring a real plan for immersive representation.

3. Methodology: Design Process of a procedural framework

The development of prerequisites and requirements, as shown in Figure 1, involved a comprehensive review of existing BIM standards, ISO 7817-1, and an analysis of needs when using immersive technologies. We integrated these elements by expanding the traditional BIM information requirements to include aspects specific to immersive experiences, such as sensory information and user interaction. Current information practices are not sufficiently clear for the virtual environment; therefore, we created a framework that accounts for this context. This integration process faced challenges in balancing the specificity necessary for immersive experiences with the broader applicability required for BIM processes. We addressed this issue by creating a flexible framework that allows customization based on user and project needs, while still maintaining the fundamental principles of BIM. The framework is divided into five parts, each with specifications to structure outputs useful for the next phase, as listed below:

- Case Study: This initial phase involves selecting and analysing a specific project or building, including survey campaigns and BIM modelling. It provides the foundation for subsequent immersive representations.
- Definition of Prerequisites and Requirements: This crucial step involves defining the informational and immersive needs. It covers aspects such as purpose, timelines, involved stakeholders, and the nature of the immersive experience.
- Information Exchange Processes: This part focuses on defining protocols for sharing and collaborating on the immersive BIM model, ensuring smooth communication among all stakeholders.
- Tender Procedure: This section adapts traditional BIM tender processes to incorporate immersive requirements, including the development of Exchange Information Requirements (EIR) that consider immersive aspects.
- Iteration: The final part involves a cyclical process of testing, evaluation, and refinement. It allows continuous improvement of the immersive BIM workflow based on practical application and user feedback.

Through this framework, we aim to obtain the information needed to design a plan for representing information in a digital environment, which can be traditional or advanced immersive, depending on the outlined purposes.

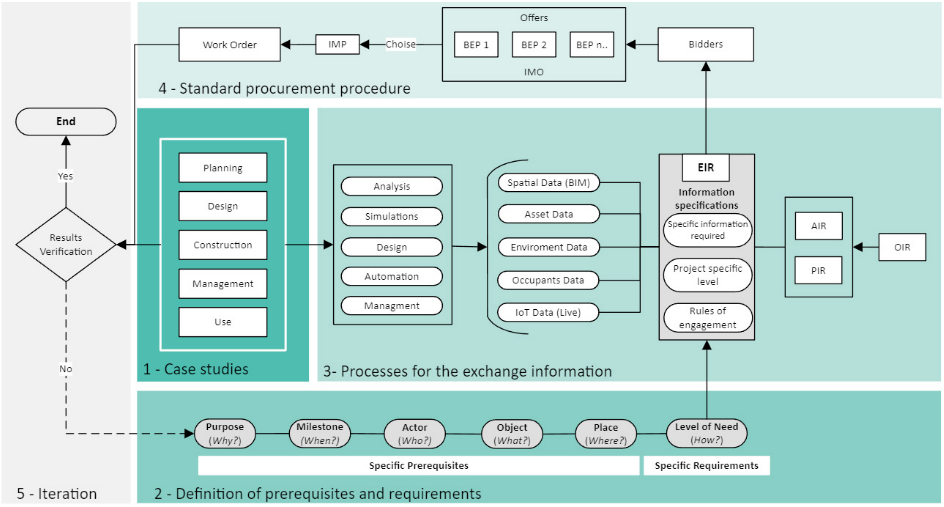


Fig. 1 A procedural framework for immersive programming in virtual environments.

3.1. Case studies: Survey and Modelling

The first section of the framework involves choosing a case study. In our specific case, we focused on the Borgo Pirelli district in Milan [22], where several survey campaigns were conducted using laser scanning equipment on some sample buildings, followed by modeling through Autodesk Revit. The ultimate goal was to create simulations for visualizing a BIM model and the context within a service conference for a feasibility study and make aligned and clear decisions regarding the current state. The survey campaign was set up with a Leica RTC 360 scanner and a Leica BLK2GO laser. The campaign involved five sample buildings, mapping the 5 typologies that make up the district. The point clouds obtained were pre-aligned cloud to cloud in situ with the Cyclon FIELD app and then registered with Register 360. The resulting point clouds were exported in an interoperable format (.e57) and imported into Autodesk Recap to be read during modeling in Revit. Once modeled, the five buildings were georeferenced, creating a file containing the master plan. At this point, the objective was to test the framework and its implementation phases with immersive technologies.

3.2. Prerequisites

Starting from the guidelines established in the ISO 7817-1 standard, which provides an initial definition of the concept of "Level of Information Need," we have developed a series of prerequisites and requirements. These have been formulated considering a wide range of aspects already examined during the analysis of literature and regulatory context [3]. To this end, the following specific prerequisites and requirements have been identified in combination with BIM and immersive technologies, as follows. For each informational specification (Why, When, Who, and What), not only traditional digital environments are considered, but also the potential of advanced immersive technologies. In this regard, prerequisites are structured with a more detailed informational granularity, Table 1, considering some aspects that were previously unexplored.

- Purpose (Why?): Specifies the reason why information is required, often linked to BIM uses such as visualization, coordination, management. This varies depending on the project phases, such as planning, design, construction, management, and use.
- Timing (When?): Indicates when information is required, such as in design phases or at specific dates. This phase is crucial for setting project timelines and is divided into temporal definition and activation sequence.
- Actors (Who?): Defines the professional figures involved in the process or specific phases, such as client and designer, considering their role, responsibility, training, and personal skills.
- Object (What?): In the ISO 7817-1 standard, refers to what the Level of Information Need is associated with. The object is not only the element (e.g., door, floor, wall, installations) we are accustomed to, but it has a

broader significance, including parts, systems (e.g., ventilation system), or entire buildings [10]. In this case, "object" takes on a broader meaning, not only referring to an object or a system of objects but also to the immersive experience and sensations of users, so we can define it as an immersive ecosystem (Figure 2).

Tab. 1 Information table of prerequisites.

PREREQUISITES		
Purpose (Why?)	Planning	
Milestone (When?)	Temporal definition Activation sequence	Timeline.
Actor (Who?)	Roles Responsibility Training Skills	
Object (What?)	Immersive Experience Sensory Information Immersive Ecosystem	Activate or Passive Monosensory or Multisensory Content: Real, Digital or Virtual Enviroment: Real, Digital or Virtual

In an advanced immersive environment, if required, some or many of the information used in the traditional digital environment may not be helpful or may be limiting, as the informational framework appears incomplete and subject to the discretion of each actor who can interpret it freely. It is for this reason that we wanted to integrate the framework of prerequisites and requirements, to have a complete framework even when working with advanced immersive environments. The implementation of these prerequisites in the BIM process presented challenges, particularly in aligning the requirements of the immersive experience with existing BIM workflows. We addressed this issue by creating a parallel structure that integrates rather than replaces the traditional BIM information requirements. This approach allows for seamless integration while providing the additional details necessary for immersive applications.

3.3. Requirements: Informative and Immersive Level

The requirements represent, in a certain sense, the operational part of the process where specific granularity is given to all information. Current regulations divide the type of exchanged information, define the concepts, and how the level of information need can be satisfied, through Geometric Information, Alphanumeric Information, and Documentation. However, these concepts are addressed on a scale of traditional information representation, whereas if we talk about immersiveness, with virtual worlds and state-of-the-art immersive technologies, the lack of specific requirements [23] is evident. Finaly, it is necessary to distinguish between information that has the object's virtual or real scale (depending on the chosen flow) from sensory-perceptual information (obtained through tools, sensors, etc.). This is important because when discussing the level of information need, it only presupposes an object or system (set of objects). While if we talk about immersiveness, we cannot only talk about the object, but virtual ecosystems must be defined, composed of users, environments, and models, which together must also produce "perceptive-sensory" information [24]. In this regard, the information requirements of the ISO 7817-1 standard do not meet all the criteria when representing an immersive ecosystem, as can be easily understood from Figure 2. They have therefore been reviewed and implemented to be evaluated with simulations during application with immersive technologies. The integration of immersive requirements allows managing a series of data derived from immersive technologies within the BIM methodology without which each user should hypothesize their existence from time to time, creating vocabulary, interpretation, representation, and other issues [3,25]. Table 2 lists the informational and immersive requirements hypothesized by us. The structuring of these requirements represents an exercise in designing an information representation plan, where it is essential to consider different aspects such as behaviour, characteristics, content, and relationships. Currently, in the BIM context, it is not clearly defined how information should be represented and exchanged in an immersive environment, so it is necessary to identify the information needed for each specific phase of the process. It is important to note, from Table 2, that the informational/immersive levels are divided into membership classes, identified in four areas: Information Behaviour, Characteristics of Information, Informative Content, and Informative Relationship. For each class, a specific membership level is defined, and, in turn, for each level, the related required information is specified. Some of this information is derived from the existing ISO 7817-1 standard, while some are structured based on previously conducted analyses [3]. This study aims to address the existing gap in literature by establishing structured informational frameworks that will subsequently be implemented in specific case studies on immersive representations, enabling the evaluation of their outcomes.

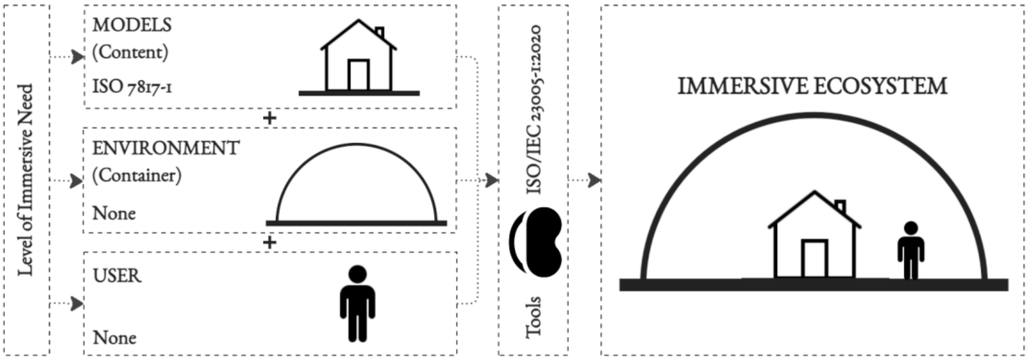


Fig. 2 Immersive Ecosystem.

Defining immersive requirements posed significant challenges, as there were no existing standards to follow. We overcame this issue by drawing on best practices from other disciplines, such as gaming, and through tests and pilot projects conducted in our previous studies. A key challenge was ensuring that the immersive requirements remained relevant and applicable to different types of projects and immersive technologies. We addressed this by creating a modular framework that can be adapted to specific project needs, while maintaining a consistent basic structure.

Tab. 2 Information framework for defining information and immersive requirements.

REQUIREMENTS			
Level of and immersive Need	**Information Behavior**	Static	Not Animated
		Dynamic	Animated
	Characteristics of Information	Visual	Geometric
			Graphics
			Textual (alphanumeric)
		Auditory	Sound effects
			Audio tracks
			Verbal discussions
		Advanced	Audiovisual (Mixed)
			Physical model (Tactile)
			Environmental aromas (Smell)
	Informative Content	Geometrical Infromation	Detail
			Dimensionary
			Location
			Appearance
			Parametric behavior
			Texture (gradual scale)
			Lighting
			Depth of field
		Alphanumerical Information	Identification
			Infromation content
		Documentation	Set of documents
	Informative Relationship	Traditional	Manual
			Visual programamtion
			Text-based programming
		Advanced	AI System
			ChatBot
			GPTS
			Singleton

3.4. Standard procurement procedure and Iteration

Once the prerequisites and requirements are structured, the practical procedure, during public tenders with BIM methodology, involves defining an EIR (Exchange Information Requirement) that collects not only informational and immersive contents but also a series of external documents reflecting Commercial, Management, and Technical parts (OIR - Organizational Information Requirements; AIR - Asset Information Requirements; PIR - Project Information Requirements). Subsequently, during the proposal phase by the competitors, the technical information offer must conform to the EIR and the specification previously developed by the client, and then, after the award, the information plan must follow the same requirements and prerequisites required upstream. This process should include requirements and prerequisites that take into account the immersive aspects previously investigated. Without initial guidelines, the production and exchange of information defined by the EIR for immersive technologies do not allow the drafting of specific plans structured for these purposes. This can create a cycle of limitations for contractors, both in pre-contractual and post-contractual phases (Information Management Offering – IMO and Information Management Plan - IMP), impairing the entire production cycle of a work. Consequently, the lack of clear and specific parameters and requirements can slow down the effective adoption of these technologies. Following the Design Science Research Methodology (DSRM), a phase of verification and control of the results is foreseen, and if necessary, possible adjustments with related iterations in the cycle described above to improve and adjust prerequisites and requirements, and consequently all the subsequent documentation described above. It should be noted that in this research project only phases one, two, and five of the framework have been implemented. Therefore, any future developments in collaboration with public administrations may also consider a complete analysis structure.

4. Experiments and simulations with Case Study

In addition to establishing a structure of prerequisites and requirements, it was essential to define a format that was compatible with the requests of prerequisites and requirements, along with a standard that enabled operability and fostered interoperability among the platforms and tools used by stakeholders. To this end, the standard identified for managing tools and software is OpenXR, an open standard specification developed by an industry consortium, including the Khronos Group, to enable the creation of augmented reality and virtual reality applications compatible with a wide range of devices and platforms [18]. As for the format, we sought an open format that was fully interoperable with the AEC industry and allowed for easy collaboration, management of static and animated models, and an intuitive user interface. The USD (Universal Scene Description) format, developed by Pixar Animation Studios for representation, has proven to be the most suitable for our purposes.

4.1. Simulation A

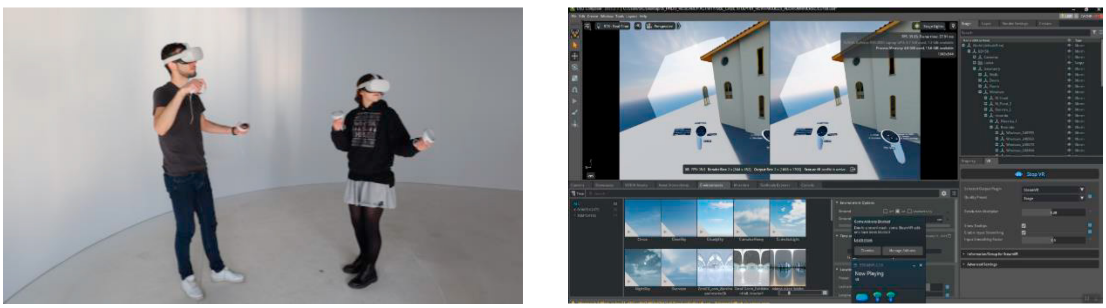


Fig. 3 (a) Virtual theater photo; (b) Screenshots of the simulations during the collaboration phase with the viewers in Omniverse.

In this initial simulation, we have elaborated the following considerations regarding the structuring of prerequisites and requirements. Regarding the purpose, we hypothesized a visual analysis of individual buildings. Since we were in a preliminary hypothesized phase, we did not deem it necessary to define milestones, while the actors involved were researchers in the field of architecture and engineering, equipped with specific and advanced skills to effectively outline this initial simulation, Figure 3. Concerning the object, we envisaged an analysis of individual buildings through a mixed immersive experience, involving interactive and collaborative interactions between the model and users. Additionally, we hypothesized the use of a single source of sensory information, limited to the sense of sight. The immersive ecosystem was virtually conceived as a series of immersive sessions, each focused on an individual unit (building), as well as the external environment.

In the subsequent phase of our work, we proceeded with structuring the requirements, which involved a detailed definition of information divided between content and the surrounding environment. These elements, along with the user previously defined by the prerequisites, constitute our virtual ecosystem with which we interact through immersive tools and technologies. Specifically, in this simulation, we focused exclusively on the content, as we hypothesized that the reproduced environment was not essential and therefore did not require modelling or detection. The informational behaviour of the model during the immersive session was configured as static, without animations. Regarding the characteristics of the information, we limited ourselves to the visualization and interaction with meshes and parametric elements, excluding audio and advanced sensors. Regarding the informational content, we based ourselves on the ISO 7817-1 standard, integrated with some additional specifications such as the graduated scale of textures, lighting, and depth of field. Finally, concerning the interaction with the information, we envisaged the use of a standard method with controllers, keyboard, and mouse. The setting of prerequisites and requirements has resulted in a clear definition not only of the necessary information but also of the most suitable tools. Particularly, for interaction with the model, user collaboration, virtual environment, and management of all the aforementioned requirements, we identified the headset as the ideal tool. Therefore, we chose to use the Meta Quest 2.

In this phase, we exported the BIM model from Autodesk Revit 2024 to the USD format, through the plugin available in NVIDIA Omniverse. Omniverse is a 3D simulation and collaboration platform that allows users to create, share, and render virtual environments in real-time. It is designed to provide an immersive and collaborative experience for professionals and developers. Subsequently, we installed Nucleus Navigator and Drive Beta within the Omniverse Launcher library. These two extensions allow the creation of a cloud server and groups for sharing in the virtual environment. Once the devices were connected, we initiated collaboration with two users.

4.2. Simulation B

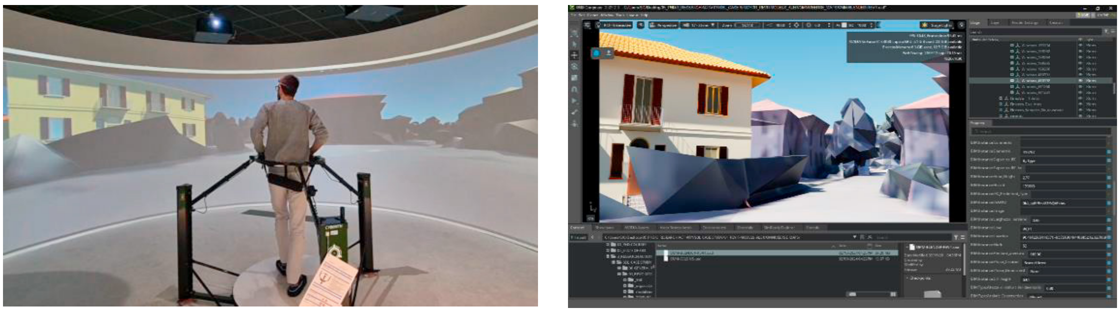


Fig. 4 (a) Photo portraying the user while walking inside the virtual theatre; (b) Omniverse setup.

In the context of simulation B, Figure 4, we modified the structure of prerequisites and requirements compared to simulation A. The purpose remains a visual analysis of the buildings, extended to the surrounding environment. We did not define timings, remaining in a hypothetical phase, and the actors involved were three researchers. The analysis involves a collaborative immersive experience without direct interaction with the model, but with the ability to move within the environment. We hypothesized the use of only one sensory source, limited to sight. The immersive ecosystem was conceived as a single entity, including the individual units modelled previously. Compared to the previous case, we structured different prerequisites and informational requests to obtain a more comprehensive virtual ecosystem, focusing on both content and the surrounding environment. The informational behavior of the model was configured as static without animations, with limitations on visualization and exclusion of audio and advanced sensors. We detailed the informational content, including details, dimensionality, textures, lighting, not only for the content but also for the surrounding environment. For interaction, we envisaged the use of a VR platform to allow users to walk within the model, simulating the physical experience. The results thus suggested the use of the Virtual Theater at the Labora Laboratory of the Politecnico di Milano since direct interaction with the model was not expected.

Regarding the walking hypothesis, we integrated a specific Toolkit of the Cyberith Virtualizer ELITE 2, thereby enabling this functionality. During this phase, we utilized the BIM models previously exported to the USD format via the plugin available in NVIDIA Omniverse. Subsequently, we reconstructed the surrounding environment using the Cesium ion plugin for Omniverse, which allows the recreation of the entire 3D context using Google Maps 3D or Bing data. At this point, the USD file containing all the information was imported into Unity (the software with which the Virtual Theater interacts for model visualization) via the plugin present in the Omniverse Launcher library, and we initiated the simulation.

4.3. Simulation C

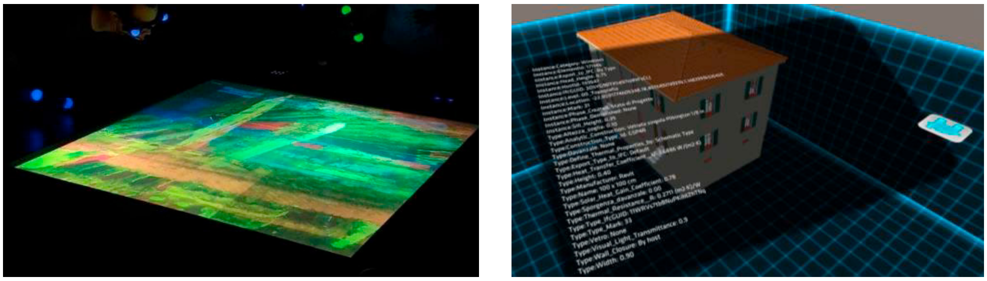


Fig. 5 (a) Hologram Table photo; (b) Screenshots during the collaborative phase of viewing and interrogating the BIM model.

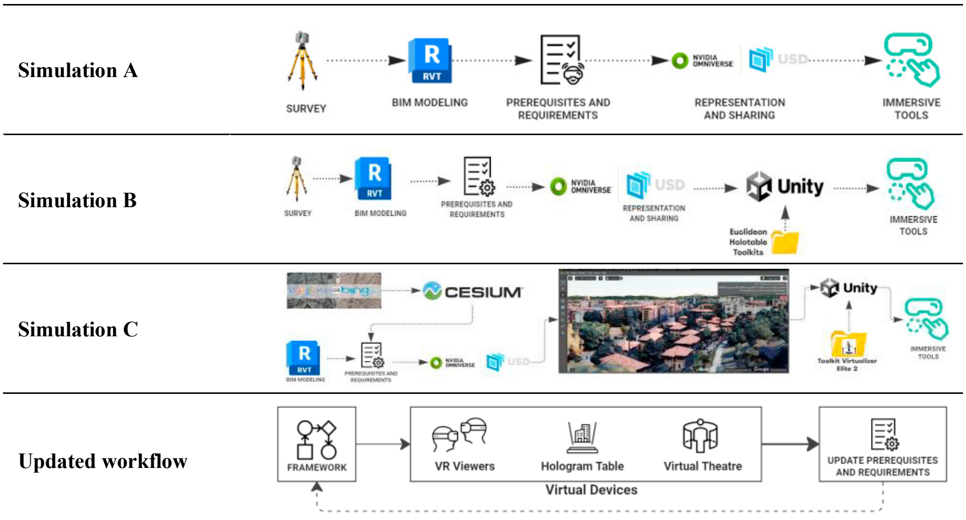
Finally, we have reviewed the prerequisites and requirements, this time considering the visualization of the BIM model not only from a geometric standpoint but also from an informative one, Figure 5. Regarding the purpose, we have maintained the hypothesis of a visual analysis of the buildings, but we have added the necessity to also display the parameters associated with the geometries. We have not defined any timelines as we are still in hypothetical simulations, and the involved actors have remained the same. The analysis entails a collaborative and iterative immersive experience with the model, allowing users to manipulate objects as in the simulation of the previous simulation A. We have hypothesized the use of a single source of sensory information, limited to the sense of sight. The immersive ecosystem has been virtually conceived as a single entity (building), without modeling the surrounding environment. In structuring the requirements, we have focused on the visualization of parameters and collaborative interaction among multiple users. The informative behavior of the model during the immersive session has been configured as static, without animations, and we have excluded audio and advanced sensors. The informative content has focused on the alphanumeric and geometric part, including details, dimensionality, texture, lighting, etc. For interaction with the information, we have envisaged the use of traditional controllers. For interaction with the model and reading of the parameters, the data directed us towards the use of the Hologram Table at the Labora Laboratory of the Politecnico di Milano. Visors could also be a valid alternative, but they presented limitations in reading BIM parameters. In this phase as well, we utilized the BIM models previously exported to the USD format via the plugin available in NVIDIA Omniverse. To implement the projects within the Hologram Table, we used the template provided by the parent company EuclideonHolotableToolkits, onto which the USD models were imported. Subsequently, we performed the project build and initiated the simulation.

5. Results and Future Developments

From the described simulations, it becomes evident that the granularity of the information required for a model varies based on the specificity of each simulation. Elements such as behaviour (static or dynamic), related geometric information, and the clear definition of environmental boundaries are essential for visual simulations or virtual immersions but may not be included in the BIM model. Defining a level of informational and immersive needs can facilitate the creation of comprehensive immersive simulations in terms of data for future use.

Through the three case studies, we confirmed this possibility. The clear definition of prerequisites and informational and immersive requirements allowed for a better understanding of the necessary data and the most suitable tools for each simulation. The choice of tools was guided by the specificity of the informational and immersive requirements. For example, we selected headsets for simulation A, favouring model interaction and collaboration; Virtual Theater for simulation B, facilitating collaboration and walking simulation; and finally, the Hologram Table for simulation C, to enhance interaction with the model and the reading of BIM parameters. We also identified some issues and potential improvements to address in the future. It emerged that prerequisites and requirements should be defined before the start of the survey campaign, as indicated in Table 3, and not only afterwards. The variable use of immersive prerequisites and requirements has different impacts on the objects, tools, and users involved. The integration of these prerequisites and requirements into the BIM process revealed challenges in data management and interoperability. Existing BIM software and processes are not always equipped to handle the additional data required for immersive experiences. We are addressing this issue through ongoing research on data structuring. Furthermore, the subjective nature of immersive experiences poses challenges in standardizing requirements. We are developing more robust user testing protocols to better quantify and standardize this subjective data.

Tab. 3 Simulation workflow A, B, C and updated workflow.



After this consideration the Level of Immersive Need cannot be standardized, as during the immersive phase there is a subjective component that leads to personalized perceptions of the experience, varying from user to user. However, keeping the goal fixed, everyone's attitude modifies the Level of Immersive Need. Therefore, it is necessary to broaden the validation test by involving a greater number of volunteers with diverse skills and ages. It is crucial to structure a questionnaire to collect data and validate the experience of each user, to obtain a more comprehensive overview of the framework functioning and immersive requirements. Additionally, the prerequisite defining the timing in simulations should be considered for future developments, as it could have a significant impact [26]. Of fundamental importance for the validation of the structured framework will be the expansion of the number of tests across a greater number of case studies and pilot projects to ensure its robustness and applicability in various contexts. Including additional case studies covering a wider range of sectors and applications can help validate the flexibility and applicability of our framework. Implementing the framework in new contexts such as new residential construction, the healthcare sector, and large-scale infrastructure projects could provide more robust validation. Initiating pilot projects that involve partnerships with industry companies and public administrations to test the framework in real-world scenarios will be crucial. Involving universities and research institutes to develop further comparative studies that analyze the framework's effectiveness in various environments and with different users, even under different regulatory contexts, through controlled experiments and longitudinal studies, will provide detailed data on the use and impact of the framework. Each new case study should be designed to test specific aspects of the framework, providing useful comparative data. Further research could focus on evaluating the impact of immersive technologies on user productivity. Through longitudinal studies, we can determine if and how these technologies affect workflow and project outcomes. The developments foresee a timeline developed over the next five years, divided as follows:

- In the first year, it is planned to expand the number of validation tests with a greater number of volunteers to widen the user base for framework validation.
- In the second and third years, the priorities will be the development and implementation of advanced sensors and the initiation of new case studies in different sectors.
- In the third and fourth years, the focus will be on the study of optimizing multi-user interaction and the evaluation of the impact of immersive technologies on productivity. Finally, in the fourth and fifth years, the analysis and publication of the results obtained from the expanded case studies will be conducted, along with the continuous review and improvement of the framework based on the feedback collected.

6. Conclusions

Throughout our research, we adopted a method to validate the framework consisting of structuring different simulations, starting from the previously outlined case study. We simulated a collaborative meeting for the preliminary planning of a project, during which we hypothesized various prerequisites and requirements. We also introduced the concept of Level of Immersive Need, which differs from Level of Information Need due to its inclusion of a set of prerequisites and information requirements specific to the immersive phases. Therefore, if users need to operate in traditional digital environments, they can refer to the Level of Information Need. However, if virtual environments are involved, the structure of the immersive Level of Immersive Need allows managing the information process for this specific purpose. Subsequently, we evaluated the effects of variations in prerequisites and requirements on the final instrumentation and the immersive ecosystem being outlined. This approach allowed us to gain a better understanding of the impact of variations in prerequisites and requirements on the proposed final solutions, providing us with useful insights to optimize the decision-making process and improve adoption in the context of immersive technologies. The importance of these results and considerations will be an integral part of the continuation of our research. We plan to implement a broader validation process involving a larger number of volunteers and using specific questionnaires to collect feedback and assess the effectiveness of the framework in diversified contexts. Additionally, corrections identified in this initial phase will be made, and current simulations and case studies will be implemented. This will enable us to obtain more robust verification data in both qualitative and quantitative terms.

References

[1] Creative Europe Programme (CREA) Call for proposals Video games and immersive content development (CREA-MEDIA-2024-DEVVGIM) n.d.

[2] Monla Z, Assila A, Beladjine D, Zghal M. Maturity Evaluation Methods for BIM-based AR/VR in Construction Industry: A Literature Review. IEEE Access 2023. https://doi.org/10.1109/ACCESS.2023.3281265.

[3] Balin S, Bolognesi CM, Borin P. Integration of Immersive Approaches for Collaborative Processes with Building Information Modeling (BIM) Methodology for the AEC Industry: An Analysis of the Current State and Future Challenges. Virtual Worlds 2023, Vol 2, Pages 374-395 2023;2:374–95. https://doi.org/10.3390/VIRTUALWORLDS2040022.

[4] Panya DS, Kim T, Gu H, Choo S. Development of a Real-time BIM-VR Multi-Collaborative Design Environment. Proceedings of the International Conference on Education and Research in Computer Aided Architectural Design in Europe 2023;2:733–9. https://doi.org/10.52842/CONF.ECAADE.2023.2.733.

[5] Lin Y-C, Chen Y-P, Yien H-W, Huang C-Y, Su Y-C. Integrated BIM, game engine and VR technologies for healthcare design: A case study in cancer hospital 2018. https://doi.org/10.1016/j.aei.2018.03.005.

[6] IFC4 RV - 1.2 [Official] n.d. https://standards.buildingsmart.org/MVD/RELEASE/IFC4/ADD2_TC1/RV1_2/HTML/schema/views/reference-view/index.htm (accessed January 29, 2024).

[7] ISO 7817-1:2024 - Building information modelling — Level of information need — Part 1: Concepts and principles n.d. https://www.iso.org/standard/82914.html (accessed July 26, 2024).

[8] Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S. A design science research methodology for information systems research. Journal of Management Information Systems 2007;24:45–77. https://doi.org/10.2753/MIS0742-1222240302.

[9] Ozturk GB. Interoperability in building information modeling for AECO/FM industry. Autom Constr 2020;113:103122. https://doi.org/10.1016/J.AUTCON.2020.103122.

[10] UNI EN 17412-1:2021 - UNI Ente Italiano di Normazione n.d. https://store.uni.com/uni-en-17412-1-2021 (accessed July 18, 2023).
[11] Zhang C, Perkis A, Arndt S. Spatial immersion versus emotional immersion, which is more immersive? 2017 9th International Conference on Quality of Multimedia Experience, QoMEX 2017 2017. https://doi.org/10.1109/QOMEX.2017.7965655.
[12] Elghaish F, Matarneh S, Talebi S, Kagioglou M, Hosseini MR, Abrishami S. Toward digitalization in the construction industry with immersive and drones technologies: A critical literature review. Smart and Sustainable Built Environment 2021;10:345–63. https://doi.org/10.1108/SASBE-06-2020-0077.
[13] Ventura SM, Castronovo F, Ciribini ALC. A design review session protocol for the implementation of immersive virtual reality in usability-focused analysis. Journal of Information Technology in Construction 2020;25:233–53. https://doi.org/10.36680/j.itcon.2020.014.
[14] Pilkington R. Silicon: From the Invention of the Microprocessor to the New Science of Consciousness by Federico Faggin. Journal of Scientific Exploration 2021;35:687–92. https://doi.org/10.31275/20212205.
[15] Faggin F. Possibilities are quantum. Https://DoiOrg/101177/27538699221142510 2023;1:67–72. https://doi.org/10.1177/27538699221142510.
[16] FAGGIN FEDERICO. IRREDUCIBLE : consciousness, life, computers, and human nature. 2024.
[17] Faggin F. SARÀ POSSIBILE FARE UN COMPUTER CONSAPEVOLE? n.d.
[18] Jahnke C, Jäkel J-I, Bott D, Meyer-Westphal M, Klemt-Albert K, Marx S. BIM-based immersive meetings for optimized maintenance management of bridge structures. Ce/Papers 2023;6:681–90. https://doi.org/10.1002/CEPA.2009.
[19] Boton C. Supporting constructability analysis meetings with Immersive Virtual Reality-based collaborative BIM 4D simulation. Autom Constr 2018;96:1–15. https://doi.org/10.1016/J.AUTCON.2018.08.020.
[20] Abbas A, Choi M, Seo JO, Cha SH, Li H. Effectiveness of Immersive Virtual Reality-Based Communication for Construction Projects. KSCE Journal of Civil Engineering 2019;23:4972–83. https://doi.org/10.1007/S12205-019-0898-0.
[21] Liu Y, Castronovo F, Messner J, Leicht R. Evaluating the Impact of Virtual Reality on Design Review Meetings. Journal of Computing in Civil Engineering 2019;34:04019045. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000856.
[22] Mazza Luigi, Gregotti Vittorio, Bolocan Goldstein Matteo. Trasformazioni a Milano : Pirelli Bicocca direttrice nord-est 2003.
[23] Kim JI, Li S, Chen X, Keung C, Suh M, Kim TW. Evaluation framework for BIM-based VR applications in design phase. J Comput Des Eng 2021;8:910–22. https://doi.org/10.1093/JCDE/QWAB022.
[24] Lee L-H, Braud T, Zhou P, Wang L, Xu D, Lin Z, et al. All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda 2021. https://doi.org/10.48550/arxiv.2110.05352.
[25] Khan A, Sepasgozar S, Liu T, Yu R. Integration of BIM and Immersive Technologies for AEC: A Scientometric-SWOT Analysis and Critical Content Review. Buildings 2021, Vol 11, Page 126 2021;11:126. https://doi.org/10.3390/BUILDINGS11030126.
[26] Castronovo F, Silva MB, Ventura SM, Akhavian R. A First Step in Generating a Decision-Making Framework for the Development of Interactive Workspaces. Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation - Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2019 2019:39–47. https://doi.org/10.1061/9780784482421.006.