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EXTENDED REALITY IN EDUCATION: EXHIBIT DESIGN AND DIGITAL REPRESENTATION FOR MUSEUMS

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Abstract

The role of Extended Reality (XR) in education is growing within universities and offers valuable research opportunities in interdisciplinary development. This contribution illustrates the didactic activity of the 2023/2024 seminar 'Inside the Museum', which utilises XR for communicating architectural design projects. The course integrates exhibit design with digital technologies in the museum sector and introduces students to open and web-based AR and VR tools. Students learn the fundamentals of HTML for developing applications using ar.js, and GitHub as a repository for teaching activities. The teaching staff collaborates in creating digital content for classroom exercises, fostering shared and guided learning through innovative teaching approaches. The digital assets developed aim to collect student design ideas and establish a replicable workflow for digital communication and representation in various disciplines.

Keywords

Extended Reality, didactic activities, exhibit design, museums, digital curators.

1. Extended Reality in Education

The COVID-19 pandemic emergency led to a significant shift in management education, particularly in the use and integration of digital technologies into the learning experience (Ratten, 2023).

Extended reality (XR), which is included in the virtual continuum (Milgram & Kishino, 1994), comprises virtual reality (VR), augmented reality (AR), and mixed reality (MR) (Fig. 1). XR, today, presents new opportunities and challenges in transforming education and architectural design by offering immersive and interactive experiences that enhance learning and creativity.

It is also important to note the impact of virtual reality today, particularly with the advent of the Metaverse and the potential offered by web-based solutions for digital interaction in virtual spaces, as observed in Social Virtual Environments (SVEs) that use virtual reality as a social platform (Wei et al., 2025).

Educational institutions and design practices are increasingly integrating these technologies, presenting novel opportunities to engage students and professionals, making design concepts more accessible, and fostering a deeper understanding of spatial relationships and architectural design principles (Wang et al., 2024; Guo et al., 2021). The growth of XR in educational settings underscores

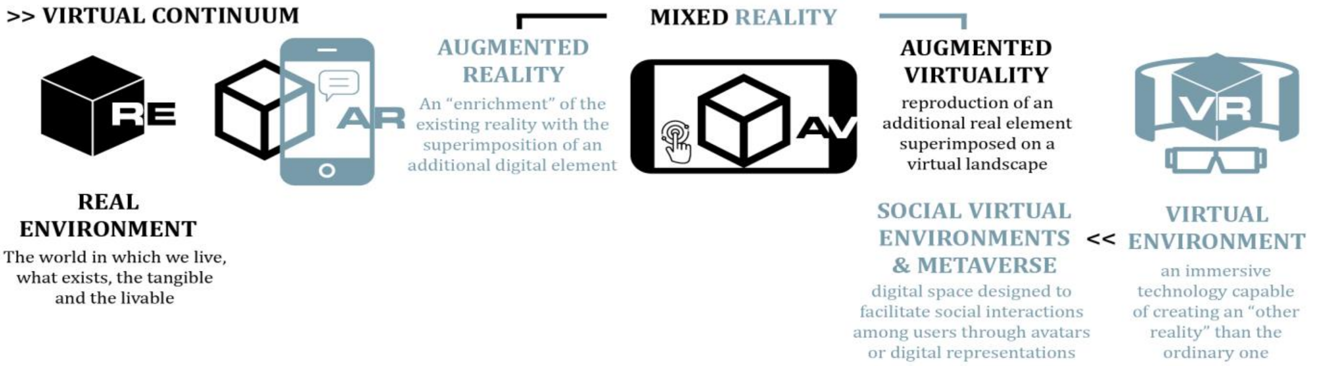


Fig. 1: The *Virtual Continuum* from Real Environment to Virtual Environment (author: J. Bono).

its potential to transform traditional approaches, fostering greater engagement and collaboration among learners and professionals.

This method has proven effective in academic environments, enhancing student engagement and retention. Research indicates that experiential learning, facilitated by XR technologies, can significantly improve knowledge acquisition compared to conventional teaching methods (Crolla et al., 2024).

Using XR in architectural design activities comprises diverse fields and disciplines, including Landscape Engineering (Liu et al., 2024), Architectural Technology (Lu, 2022), Architectural Design Studio (Hebatallah, 2024), and Exhibit Design (Caliari et al., 2024).

In architectural design, XR technologies streamline the design process and enhance client engagement by enabling real-time feedback and iterative design capabilities. This empowers architects and students to visualise and manipulate designs dynamically, facilitating collaboration across geographical barriers (Zhang, 2020).

Integrating digital technologies into education and architectural design raises significant questions concerning authenticity, accessibility, and pedagogical strategies. Ensuring, for example, that virtual environments reflect real-world scenarios and are inclusive for diverse learners is essential for maximising their educational impact.

Despite its potential, numerous challenges persist in integrating XR in education. These challenges include the cost of hardware and software, the need for adequate technical support, and the availability of tools that align with curricular goals. Furthermore, educators require training to incorporate XR effectively into their teaching practices, underscoring the need for digital literacy. However, despite these difficulties, it is possible to affirm that XR enhances collaboration and communication among stakeholders (Kharvari & Kaiser, 2022).

Designers and clients can engage in real-time feedback and iterative design processes, significantly reducing the time and costs associated with traditional methods. The same approach was replicated within the didactic activities of the Introductory Seminar 'Inside the Museum' in synergy with the Museo Archivio Reale Mutua in Turin. The course is offered to students enrolled in the master's degree programmes in the Department of Architecture and Design at the Polytechnic of Turin.

The didactic activity and, in general, the development of XR solutions primarily concern the use and reuse of data. All the digital assets created can be reused for diverse purposes or eventually post-processed to fit the needs of specific applications and tools. The digital ecosystem created for this activity is generally heterogeneous and requires optimising digital content creation processes. As illustrated in Fig. 2, the digital ecosystem mirrors the museum ecosystem, which consists mainly of a container (museum) and content (collection).

Today, digital technologies enable the integration of these two elements through digital storytelling, where narration is made possible by the stories of objects (documentation) and their biographies, which serve as a collective historical memory.

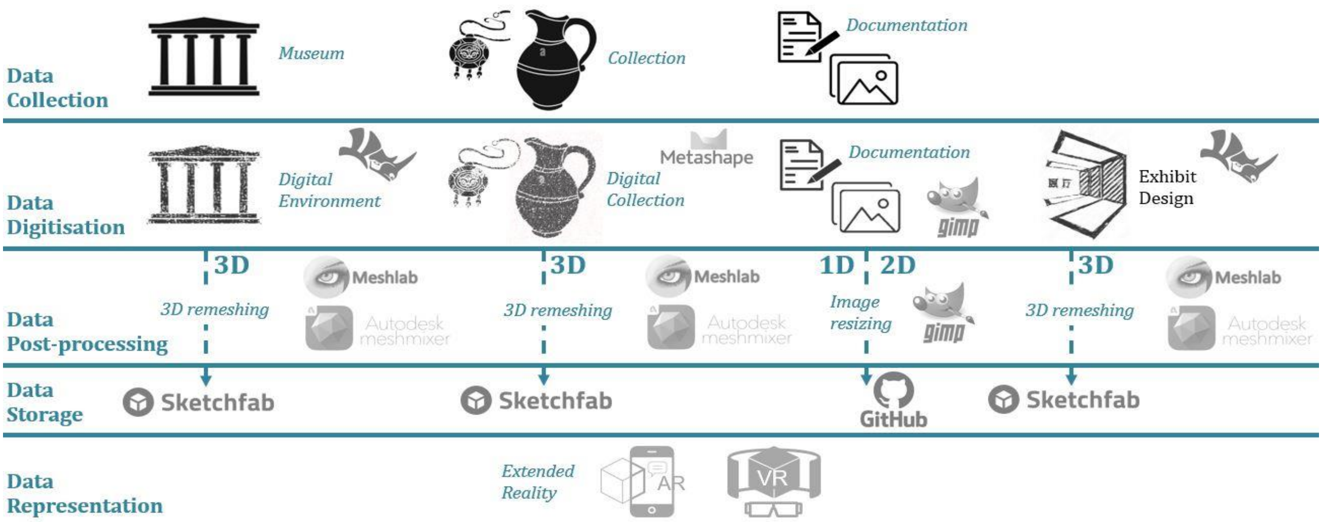


Fig. 2: Digital assets, ecosystems, and processes for XR development (author: E.C. Giovannini).

The uniqueness of the experience described below brings the teaching experience closer to the theme of promoting and communicating cultural and museum heritage (Buhalis & Karatay, 2022). In this sense, literature is rich in ideas and examples, including experiences that often aim to develop specific applications (De Marco, 2025; Clini et al., 2023; Mezzino, 2023). However, the activity described intends to use open, web-based tools, which make the applications created by students less customised but more accessible, not only to the end user but also to learners facing the challenge of developing XR applications for the first time.

1.1 Social Virtual Environments & Metaverse

Social Virtual Environments (SVEs) have become progressively key platforms in educational innovation, particularly in fields such as architecture, where spatial reasoning, collaboration, and visual communication are fundamental. Initially emerging from early multi-user environments such as MUD, Multi-User Dungeons (1980), and later evolving into 3D graphic platforms like Active Worlds (1995) e Second Life (2003), SVEs were initially designed for distant social interaction. Today, they are increasingly framed within the broader category of learning environments due to their ability to integrate immersive reality, real-time interaction, and digital storytelling using online resources (Sen, 2024; Sopher et al., 2017; Bennet, 2008).

The ongoing evolution of these platforms—often driven by cross-platform accessibility, web-based interfaces, and integration with AI-based design tools—positions SVEs as pivotal in preparing students for a digital-first profession. The ability to simulate, communicate, and iterate design proposals in immersive, networked environments supports not only the acquisition of technical skills but also the cultivation of critical, reflective, and collaborative mindsets necessary for contemporary architectural practice.

The impact of SVEs on architectural education lies in their potential to replicate and enhance the collaborative nature of design studios. These virtual spaces enable real-time teamwork, peer feedback, and co-design practices that reflect the dynamics of physical studio environments (Ramesh, 2025; Bombari, 2015). The immersive and interactive qualities of SVEs are particularly valuable in courses focused on spatial understanding, enabling students to explore projects at full scale, assess design decisions from within the space, and simulate user experience scenarios that transcend the limitations of traditional 2D representation (Cao et al., 2024).

However, the diffusion of SVEs in architectural curricula presents challenges. High initial costs for hardware, disparities in digital literacy among students and instructors, and issues related to data privacy and psychological discomfort in immersive settings present significant barriers to the widespread implementation of SVEs (Bennet, 2008). To address these concerns, educational institutions have adopted strategies such as partnerships with technology companies, using open-source platforms, and designing inclusive user experiences to ensure broader accessibility (Roudavski, 2010).

Integrating virtual reality (VR) and augmented reality (AR) tools into SVEs has proved essential. These technologies enable students to develop advanced design competencies, navigate digital twins of their projects, and overlay information-rich content for a layered interpretation of architectural intentions and concepts (Gattupalli, 2024; Crolla et al., 2024; Spitzer et al., 2022; Gomez-Tone et al., 2022). When coupled with real-time communication features, such as voice chat, gestural recognition, and collaborative object manipulation, SVEs evolve into robust ecosystems for experiential learning, aligning with pedagogical frameworks that prioritise active engagement and reflection (Table 1).

Platforms such as Mozilla Hubs and Frame facilitate accessible virtual classrooms equipped with tools for real-time discussions, media sharing, and interactive collaboration.

Spatial and Stageverse bring creativity to life, making them ideal for showcasing art, design, and performance projects in engaging 3D environments.

For gamified and experiential learning, The Nemesis presents interactive scenarios that make education playful and dynamic, while VRChat fosters informal, social learning such as language exchange and peer-led sessions.

Omniverse and Webspaces enable real-time 3D design and simulation, applicable to various disciplines, including engineering and architecture.

Collectively, these platforms provide a flexible toolkit for educators to create meaningful and future-ready learning experiences across various disciplines.

Tab. 1: Analysis of diverse SVEs solutions (author: J. Bono).

Social Virtual Environments (SVE)	Interactions							Devices
	Chat	*Voice*	*Cam*	*Draw*	*Movement*	*Mobile*	*Desktop*	*VR headsets*
STAGEVERSE	•			•		•	•	•
SPATIAL	•	•	•		•	•	•	•
VR CHAT	•	•		•	•		•	•
MOZILLA HUBS	•	•	•	•		•	•	•
THE NEMESIS	•				•	•	•	•
OMNIVERSE	•	•			•		•	•
WEBSPACES	•	•				•	•	•
FRAME	•	•				•	•	•

On the technical side, the development and use of SVEs often hinge on distinguishing between immersive environments (the container) and interactive assets (the content). Students construct spatial containers using 3D models while populating them with digital artefacts such as images, videos, and sounds that convey project narratives or simulate environmental conditions. Platforms like Mozilla Hubs and Frame have emerged as exemplary models: the former for direct interaction with content and the latter for flexibility in scene customisation.

2. *Inside the Museum Seminar*

The didactic activity conducted provides an overview of extended reality (XR) tools for cultural heritage and interior design communication within museums. Since 2022, various museum contexts have been explored, including the Royal Museums of Turin (Giovannini & Ronco, 2022), this Lingotto complex, which comprises the Pinacoteca Giovanni e Marella Agnelli and the Pista 500 (Giovannini et al., 2024), as well as the company museum of Reale Mutua in Turin (Museo Archivio Reale Mutua, n.d.) and the archaeological area of Libarna. The educational activities faced the theme of museum exhibit design, incorporating digital technologies and developing various extended reality applications.

This paper illustrates the activities undertaken during the academic year 2023/2024 in collaboration with the Museo Archivio Reale Mutua in Turin. Engaging with the museum was essential for the educational activity to replicate the relationship between the designer and the client closely. The themes identified for the exhibit design proposal should encompass the core values of the Reale Mutua Group, inspired by the fundamental concept of mutuality: integrity, the centrality of individuals, responsibility, cohesion, and innovation.

From the outset, discussions between museum curators and professionals were organised to comprehend the museum's needs (Fig. 3).

Fig. 3: Plenary meeting between students and Museo Archivio Reale Mutua curators.

Unlike other collaborations, this didactic activity involved a company museum that housed both tangible and intangible heritage, to design the layout for a temporary exhibition.

Concurrent with the design phase of the architectural project, the digital experience design was also pursued, fulfilling a dual role: on the one hand, utilising digital technologies to enhance the cultural visit, and on the other, employing XR to convey the project design.

The students enrolled in the introductory seminar were organised into groups of three to four members, each responsible for developing a design solution for the museum exhibition in both indoor and outdoor contexts.

In a.a. 2023/2024, the seminar involved 71 students across 19 groups, with a majority from the MACC track. The mix of academic backgrounds shaped different approaches to XR, combining Virtual Reality, Augmented Reality, Heritage Mapping, and Video Storytelling (Tab. 2).

Tab. 2: Composition and XR activities - Inside the Museum Seminar 2023/2024

Category	Details
Academic Year	2023/2024
Total Students	71
Number of Groups	19
Master's Tracks	
MACC [Architecture Construction City]	51 students (72%) [13 groups]
MAP [Architecture for Heritage]	6 students (8%) [2 groups]
MASt [Architecture for Sustainability]	4 students (6%) [1 group]
other	10 students (14%) [3 groups]
XR Activities Developed	
Virtual Reality	x
Augmentes Reality	x
Heritage Map	-
Video Storytelling	-

2.1 The Museo Archivio Reale Mutua in Turin

Reale Mutua company was established in 1828, and its company museum opened in March 2007 in the Sala delle Colonne of Palazzo Biandrate Aldobrandino di San Giorgio, located on Via delle Orfane in Turin. The traditional layout, featuring wooden showcases and tables, displayed over 500 documents selected from the Historical Archive, including the company's inaugural Articles of Association, dated 1828, the Regie Patenti, and policy no. 1, with which Charles Felix of Savoy insured his Turin residence, Palazzo Chiablese.

Company museums preserve and valorise their cultural heritage by interweaving tradition, experience, and innovation. Their layouts guide visitors along emotive and captivating routes, fostering and igniting growing interest. Their role in researching, conserving, and transmitting a company's material and immaterial heritage distinguishes them from typical cultural institutions.

The museum seeks to share the Company's centuries-old history and core values, with mutuality being the foremost among them. The Friends of the Reale Mutua Museum Association, established in 2009 through the voluntary collaboration of operational members, all former employees, endeavours to maintain contact with the public interested in visiting the museum and to organise guided tours. Between 2010 and 2012, the company undertook an architectural enhancement and restoration of Palazzo Biandrate Aldobrandino di San Giorgio (Ludovici, 2012), which houses the Museum on the ground floor in a space known as 'Sala delle Colonne'. Since 2023, the Sale Auliche of Palazzo Biandrate were added to the usual visiting route. The new path was established to enhance the discoverability of Reale Mutua's headquarters for the general public and also became a challenging case study for the introductory seminar. The 'Sale Auliche' can be accessed from the inner courtyard and are situated on the first floor of the building (Fig. 4).

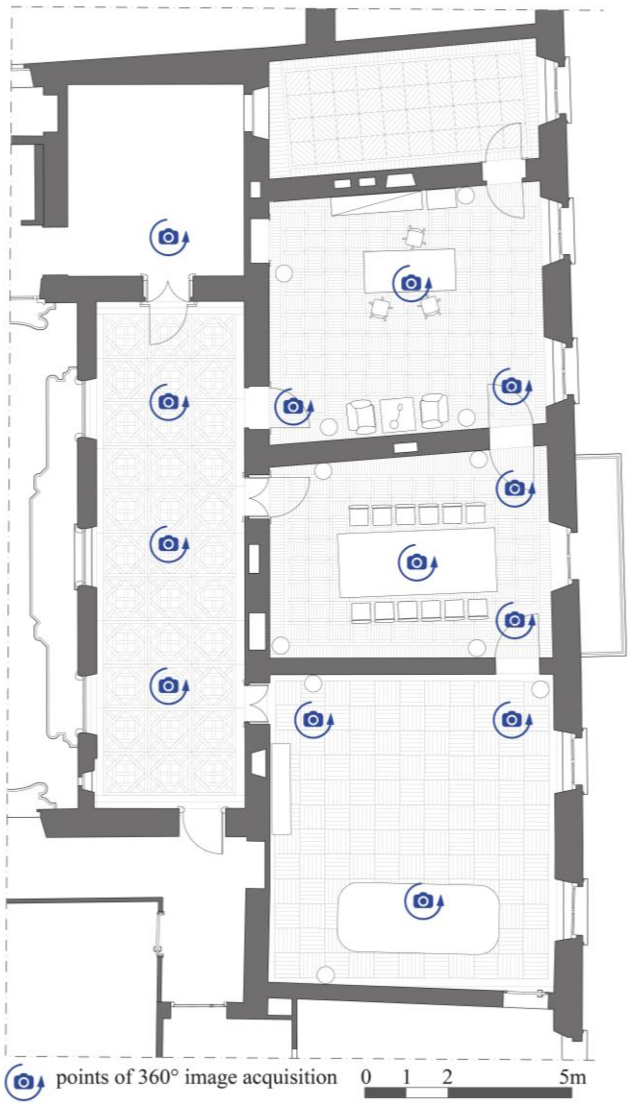


Fig. 4: Plan of 'Sale Auliche' with points of 360° image acquisition (author: E.C. Giovannini).

2.2 Extended Reality's didactic approach

The teaching activities within the course were organised and scheduled according to a workflow established over the years. The hours devoted to direct teaching were aligned with practical exercises, requiring the teaching staff to prepare supplementary materials.

The relationship between the container and content that characterises the museum ecosystem was maintained throughout the teaching activities. By 'container', we refer to the museum context and the building, which, in most cases, forms part of our architectural heritage, and in this case, the digital replica of 'Sale Auliche'. As for 'content', depending on the objective, one can consider either the museum heritage (objects, documents, and memories) or the exhibition layout.

The binomial container/content was reimagined in the digital sphere by establishing a digital museum ecosystem where the container (the design area) has been digitally acquired using various digitisation techniques. Indeed, alongside the museum exhibition proposal, students are also tasked with designing the digital and virtual aspects of the proposal: the digital curation of the exhibition.

The teaching staff, therefore, focused on preparing the preparatory material for the extended reality activities, concentrating on the container. The 'Sale Auliche' area comprises four rooms and a connecting foyer, which includes a drawing room, two representative offices, and an executive lounge.

Producing shared material also ensures alignment with the resources developed by student groups and better organisation of dissemination activities (Fig. 5).

Students were required to develop two types of augmented reality (AR) experiences.

The first involved marker-based AR, which focused on visualising additional information within the designed museum path.

The second involved an AR experience that allowed the exhibit design layout to be superimposed on a physical maquette of the 'Sale Auliche' (Fig. 6).

The maquette was created in collaboration with ModLabArch, the Department of Architecture and Design model laboratory at the Polytechnic of Turin. The physical model combines manual modelling activities with digital modelling, rapid prototyping, and 3D printing starting from the 2D CAD provided by museum professionals. The maquette was combined with the wooden patterns of the flooring that vary in each room. A square marker was placed in the centre of the foyer to anchor the AR applications developed by student groups using AR.js web-based application.

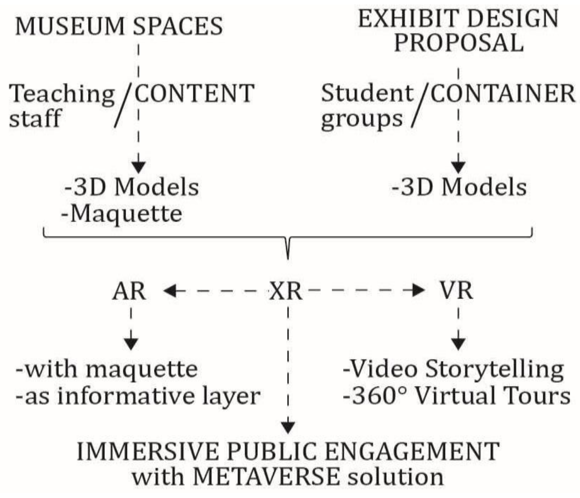


Fig. 5: Didactic activities workflow (author: E.C. Giovannini).

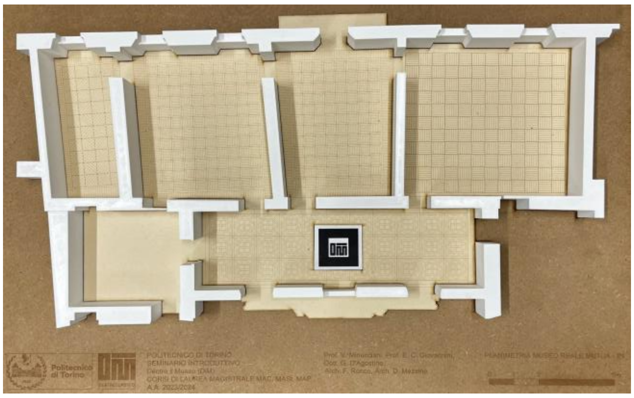


Fig. 6: The physical model of 'Sale Auliche' (author: F. Ronco, ModLabArch).

The virtual reality applications developed by student groups involve creating the new exhibit layout for the museum and developing immersive environments that enable the museum proposal to be visualised through video storytelling and 360° virtual tours.

Furthermore, in this instance, there was also a need to contextualise the content within its container: 'Sale Auliche' at Museo Archivio Reale Mutua. The digital replica of the container was created by combining three-dimensional modelling techniques with integrated digital acquisition methods: 360° camera acquisition and photogrammetric techniques.

The 360° image acquisition (Fig. 8) was made using an Insta360 X3, which provides images with a resolution of 11968x5984 Pixels. The images created a 360° virtual tour of the case study area. The virtual tour was also useful within the didactic activities to quickly visualise the case study space, which is accessible online.

The 'Sale Auliche' photogrammetric acquisition was conducted using a Sony Alpha 7R IV with a CMOS sensor (9504 × 6336 pixels). The digitised elements (e.g. vault systems) were subsequently post-processed (Fig. 9) to create and develop a digital environment composed of various digital assets and visualised online via the SketchFab platform as shown in Fig. 7.

The correspondence between physical and digital models provides the opportunity to coordinate the development of digital environments. Students can organise their exhibition design layout according to the digital space created.

Creating a virtual environment involves meticulously acquiring the features of museum rooms, such as frescoes and ceilings. Walls were simplified into surfaces textured using patterns generated through digital acquisition (e.g. wallpapers).

A diverse strategy was employed for the fresco textures: orthophotos of each wall were produced from the photogrammetric model, and then the fresco sections were selected and post-processed to develop a planar texture. When the texture was incomplete, it was enhanced to include the missing components.

The same approach was employed to create the texture of the wooden floor patterns (Fig. 10). Thanks to recognisable wooden patterns, portions of wood textures obtained from photogrammetric acquisition could be replicated, thus avoiding non-uniform colouring and reflections for a heterogeneous pavement texture.

Fig. 8: The physical model of 'Sale Auliche' (author: F. Ronco, ModLabArch).

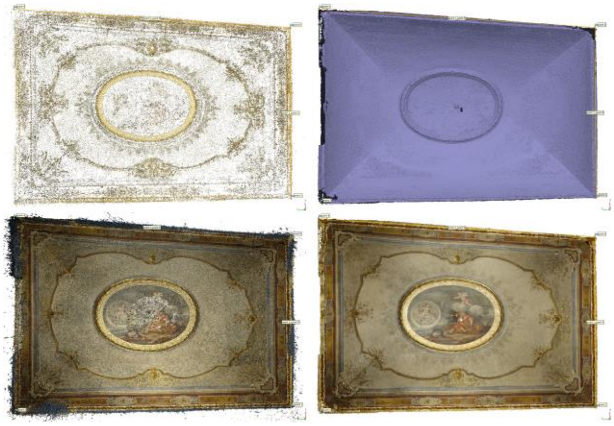


Fig. 9: Photogrammetric post-processing phases: sparse and dense cloud, 3D model and textured 3D model (author: E.C. Giovannini).

Fig. 10: pavement texture (author: E.C. Giovannini).

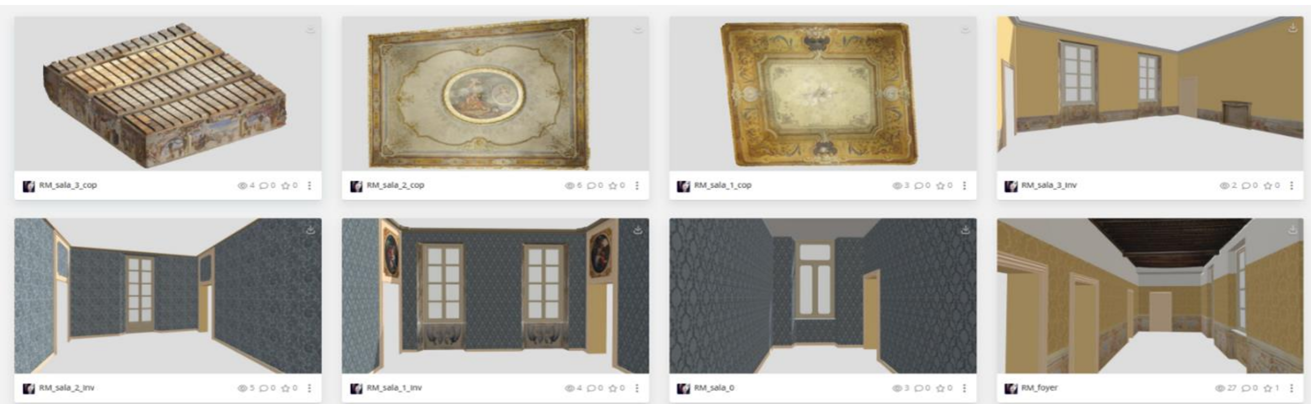


Fig. 7: 3D models collection stored in SkecthFab platform (3D models author: E.C. Giovannini).

3. *Inside the Museum Seminar*

The augmented reality experience was developed from the exhibit design project. Once the student groups had defined the layout of the exhibit, they digitally modelled it to produce renderings and videos of the design proposals (VR) and created augmented experiences (AR).

Specifically, starting from the digital model used to 3D print the physical model, the exhibit layout 3D model was aligned with the 3D model of the 'Sale Auliche' (content) provided by the professors. The origin of both 3D models must coincide to align the overlap between the maquette and the 3D representation of the exhibit design proposal (Fig. 11) using a web-based AR solution.

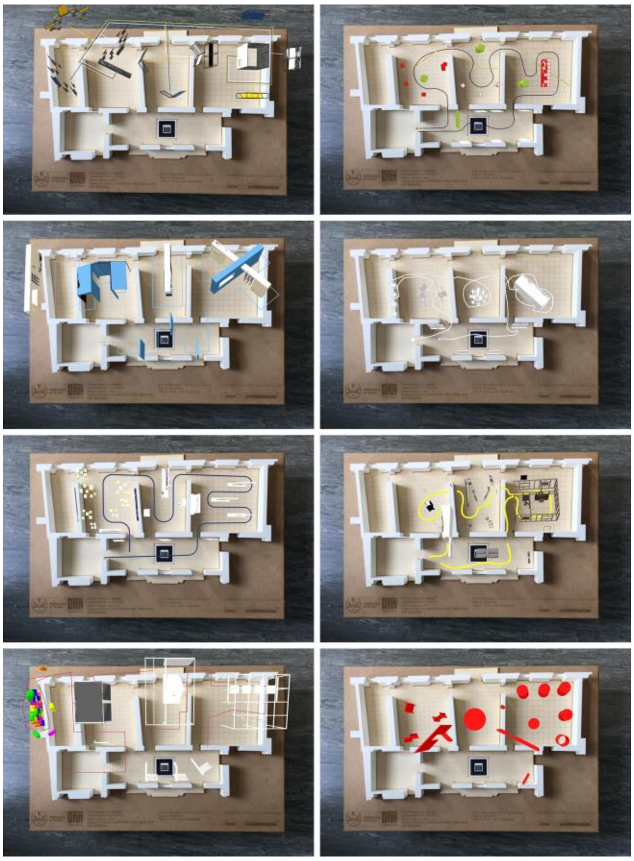


Fig. 11: Collection of some AR applications developed by student groups (author: E.C. Giovannini).

For the creation of the web-based application, AR.js (AR.js, n.d.) was employed, which integrates the libraries three.js (three.js, n.d.) and A-Frame (A-Frame, n.d.) along with jsartoolkit5 (artoolkitX, n.d.). AR.js provides two solutions: image-based and marker-based. Specifically, a marker featuring the introductory seminar logo (developed in 2022 by G. Bertola at ModLabArch) was used as a tracking marker element (Giovannini & Ronco, 2022).

Coordination for the creation of AR was conducted using GitHub as a collaborative platform for education (Zagalsky et al., 2015). Each group was instructed to create and manage their own GitHub repository in which they collected:

- the HTML page to be accessed for the augmented experience,
- a folder containing the .obj file format for setting up the 3D model,
- a folder containing the QR code developed to access the HTML page,
- a folder containing the marker and the .pat version of the same, which is mandatory for anchoring the 3D model to the physical model using the marker-based technique.

Thanks to this organisation of the experimental activity, it was possible to anchor different design solutions to the same physical model and thus consult the solutions proposed by the students in real time. To access the AR, each group created a QR code that directed users to the HTML page hosting the AR application.

Fig. 12: TeleArchitettura platform webpage dedicated to the introductory seminar Inside the Museum.

The activity was then proposed for dissemination purposes within the TeleArchitettura (TA) platform (Dentro il Museo a Reale Mutua, n.d.) (Fig. 12). The platform aims to collect and critically elaborate the teaching experiences of the Faculty of Architecture of the Polytechnic of Turin, enhancing the elements that constitute opportunities for innovation in design education and in the disciplines related to the built environment.

In this case, the AR technology utilised was image-based, which enables various design solutions to be anchored to the image of the physical model.

4. Virtual Reality web-based solution

Virtual tours and video storytelling were two primary categories of VR applications developed by students. As Tomasella (2024) highlights, virtual tours are made by three-dimensional space simulation technologies, which serve as a vehicle for sharing and enhancing understanding of spatial representation thanks to new modes of navigation (guided, free, and constrained).

The use of virtual reality (VR) applications enabled students to situate their design solutions within immersive environments, simulating real spaces both geometrically (shape) and materially (texture). This allowed each student's group to evaluate the validity of their design proposals from two perspectives: first, that of the designer, who analyses the feasibility of the exhibition design; second, that of museum users and professionals (museum curators), who assess its clarity and accessibility.

In the case of Museo Archivio Reale Mutua, the digital environment was confined to 'Sale Auliche' spaces, and virtual tours facilitate immersive interaction through a combination of diverse content (2D and 3D). With these elements, the 360° Virtual Tour assumes an essential communicative role, making the narrative of the architectural project more transparent and digitally accessible.

Virtual tours were realised through spherical panoramas and also enriched with informative content, including infographics, videos and images.

Two types of 360° Virtual Tours were developed. The first involves integrating previously acquired spherical panoramas with digital content (Fig. 13).

The second approach involves the teaching staff developing a 3D model of the container while the students design a 3D content layout. The merging of these two digital assets created a virtual environment from which rendered spherical panoramas integrated with infographics could be obtained to provide an immersive and interactive experience (Fig. 14).

From a didactic standpoint, the Virtual Tour 360° facilitates compelling storytelling of the proposed design solutions, contextualised within an immersive and user-friendly environment, supported by captivating and intuitive infographics. This clarity emerged in the early stages of testing the Webobook application (Webobook, n.d.), which was used for creating the Virtual Tours 360°.

Fig. 13: The physical model of 'Sale Auliche' (author: F. Ronco, ModLabArch).

Fig. 14: Photogrammetric post-processing phases: sparse and dense cloud, 3D model and textured 3D model (author: E.C. Giovannini).

Video storytelling is another technique that students developed to narrate and communicate their exhibition proposals (Bonacini, 2020).

The use of video for project visualisation and narration is an established practice in the field of computer graphics applied to architecture. Software such as Lumion and Enscape now enables the production of video content from textured 3D digital scenes, providing an immersive experience of digital environments (Fig. 15).

The main differences between these types of experiences lie in the interaction mode between the user and the digital environment, which can be either active (360° Virtual Tours) or passive (Video Storytelling).

Both developed VR applications can be considered in the part of virtual reality identified by Milgram and Kishino (1994) as one end of the Virtual Continuum, as they are strongly oriented towards the digital world (Skarbez et al., 2021).

Fig. 15: Video animation (content creators: E. Senato, M.F. Spada, G. Stefania).

5. Immersive Public Engagement using metaverse

The outcomes of the introductory seminar were gathered and presented through three main public engagement activities that facilitate two-way communication and learning between researchers and the public (Fig. 16). These activities aim to break down barriers between research and society, fostering mutual understanding and benefit.

Fig. 16: Public Engagements activities schema (author: J. Bono).

Two of these took place on-site and had a predominantly analogue footprint: the first involved setting up and showcasing the results achieved within a temporary exhibition hosted by Museo Archivio Reale Mutua (Reale Mutua, 2024).

In contrast, the second was part of the 'UNIGHT Researchers' Night' event, featuring an initiative entitled "Around the accessibility of museums: heritage and digital tools."

Conversely, the third activity investigated the potential of digital technology as an interface between physical and virtual reality, enabling remote and online access through web-based applications. This allowed users to access course content via everyday mobile devices, allowing a broad audience to explore and engage with the materials created by the students through screen interaction.

The on-site temporary exhibition took place from 15 February to 12 March 2024 in the 'Sale Auliche' of Archivio Museo Reale Mutua. Students provided A1 layouts summarising their exhibit design proposal.

Their composition visually summarises the key stages of the educational process involving XR technologies for exhibition design, already discussed.

Among these, we decided to describe two boards, visible on the right side of Fig. 17, which were developed by different student groups and represent an example of the didactic path's output.

The process began with the representation of the museum's 'Sale Auliche' in which each group's exhibition project was to be contextualised.

Their representation (1) was achieved through both two-dimensional drawings (plans, elevations, sections) and three-dimensional visualisations (axonometric views, exploded diagrams, spatial models).

Building on this foundation, students developed augmented reality applications (2) with a dual focus: one presenting the overall layout of the exhibition, the other highlighting specific thematic elements identified by Reale Mutua, such as fire, mental health, war, flooding, and domestic safety.

These experiences were followed by virtual reality tools (3) to enhance narrative coherence and spatial exploration. Video storytelling facilitated a sequential understanding of the proposed experience, while 360° virtual tours provided detailed and interactive navigation of the designed spaces.

All AR and VR experiences were integrated into the presentation boards through QR codes, linking the analogue display with the digital outputs and allowing users to engage directly with the projects in an immersive format.

Fig. 17: Summary of the XR-based teaching activities developed by students during the seminar, as presented in the boards exhibited at the temporary exhibition held at the Museo Archivio Reale Mutua. (author: J. Bono).

Another digital public engagement activity was developed using Social Virtual Environments (SVEs), which are characterised by two main aspects. The first involves representing and navigating a virtual three-dimensional environment (VE) that faithfully reproduces a physical environment (container). The second aspect focuses on the accessibility and interaction users can experience once they enter the social space (S) (Giovannini, 2024).

SVEs utilise social virtual reality (VR) platforms that can be considered part of the metaverse. Users immerse themselves in the digital space using VR headsets and can interact with other users as avatars in a virtual world (De Marco, 2024; Reis et al., 2024).

The approach to SVE was renewed compared to the 2022/2023 academic year, during which the applications provided by Mozilla Hubs and Spoke were tested. Due to the closure of Mozilla's servers, a decision was made to test a new platform, FrameVR.io, which has similar characteristics to the previous solution (Tab. 4).

Tab. 4: Comparison between two tested SVE platforms: Mozilla Hubs and FrameVR (author: J. Bono).

General Features	Mozilla Hubs	Frame VR
Single 3D scene in Rooms/Frames	•	•
Multiple 3D scenes in Rooms/Frames		•
Container		
Default 3D presets for scenes	•	•
Retrievable/Uploadable	•	•
Content		
Informative layer 1D: whiteboards and text, voice zone, and audio (.mp3)	•	•
Iconographic layer (2D): image, PDF, video, streaming screen	•	•
Avatar		
Customisable	•	•

The primary distinction between the two platforms is the ability to have multiple 3D scenes accessible by the same URL.

FrameVR offers the ability to manage multiple scenes within a single environment. By scene, we mean the possibility of realising within the same environment (Frame) a different configuration of the content loaded within it, managing the visibility parameter of each retrieved element.

Various elements can be integrated within the virtual space based on their nature and spatial dimensions: 1D for informational elements, 2D for iconographic content, and 3D for digital models (Giovannini & Bono, 2024). These assets are organised in a list that facilitates their retrieval, placement within the scene, and alteration of their primary properties.

Among the properties of elements available from the asset list, each loaded element has a display property that facilitates the selection of the scene where this element can be exhibited.

This feature is handy for dissemination, as it enables the presentation of various design configurations developed by students within a single virtual space. Consequently, it enables a comprehensive understanding of the proposed solutions and their relationship with the host environment.

Operationally, the materials previously created by the teaching staff for the virtual reality activities, along with the corresponding digital assets (Fig. 18), were reused and retrieved using the adopted SVE platform.

One of the preparatory activities involved the retopology process of the digital assets, which was necessary to optimise the final scene and make it easily accessible in a web-based environment. This operation reduced the number of faces in the various 3D models, thereby decreasing the memory required for their storage using open-source software such as Meshlab and Meshmixer.

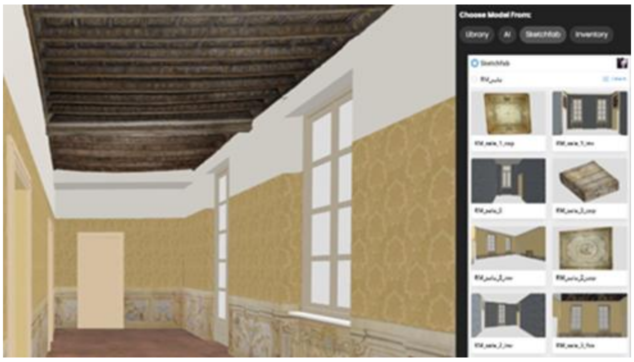


Fig. 18: FrameVR interface widget for retrieving SketchFab 3D models (3D models: E.C. Giovannini, SVE developer: J. Bono).

The final 3D scene comprises the various 3D models previously developed and retrieved using a specific function (browser library). This allows 3D resources to be retrieved directly from an external online repository by using their URL (eg. Sketchfab or GitHub).

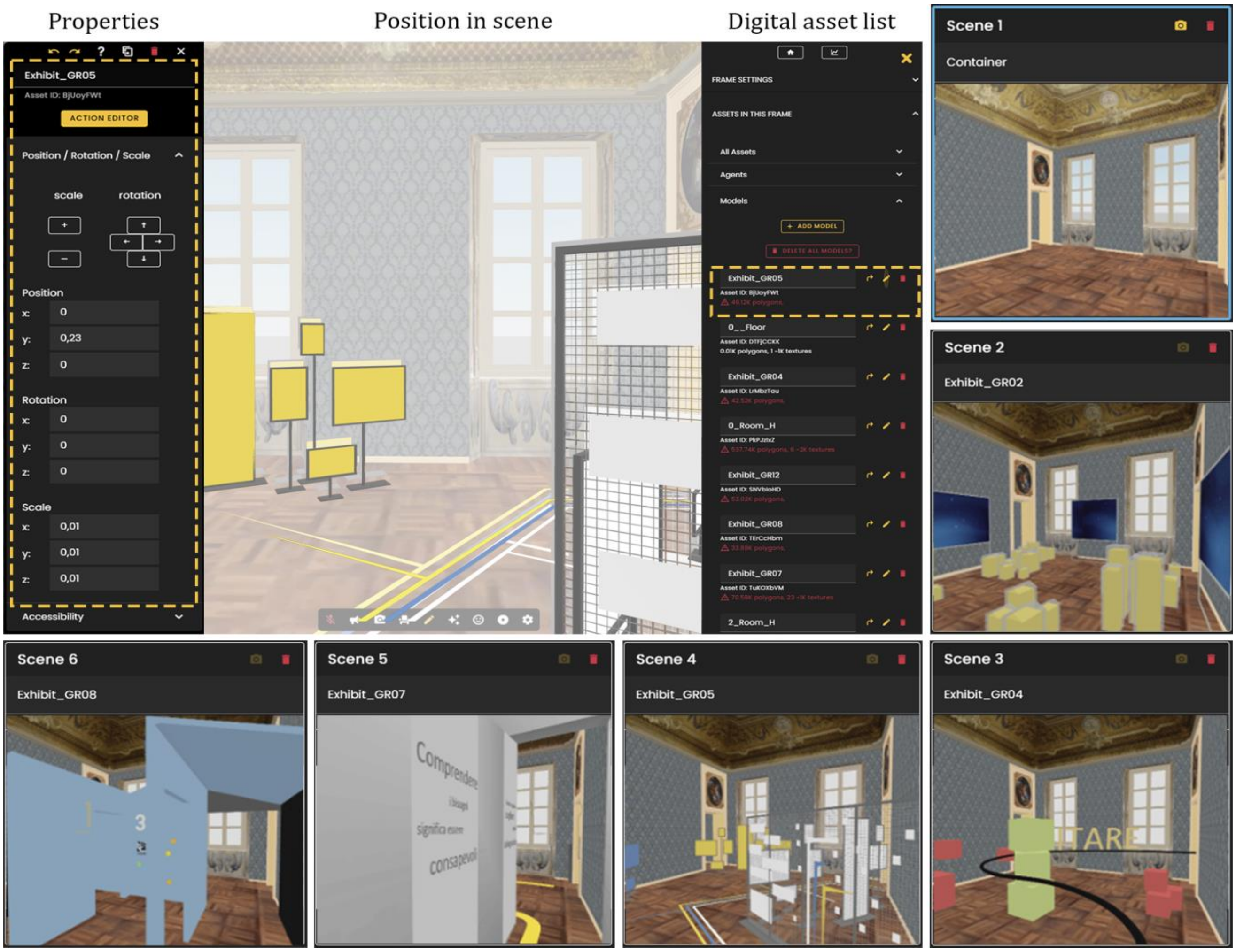


Fig. 19: FrameVR developer interface showing the list of available resources (larger image) and the organisation of multiple scenes containing diverse 3D exhibit design proposals (SVE developer: J. Bono).

This approach differs from other options that allow importing assets directly within the FrameVR interface. As shown in Tab. 3, the retrieval of 3D models from SketchFab offers more flexibility.

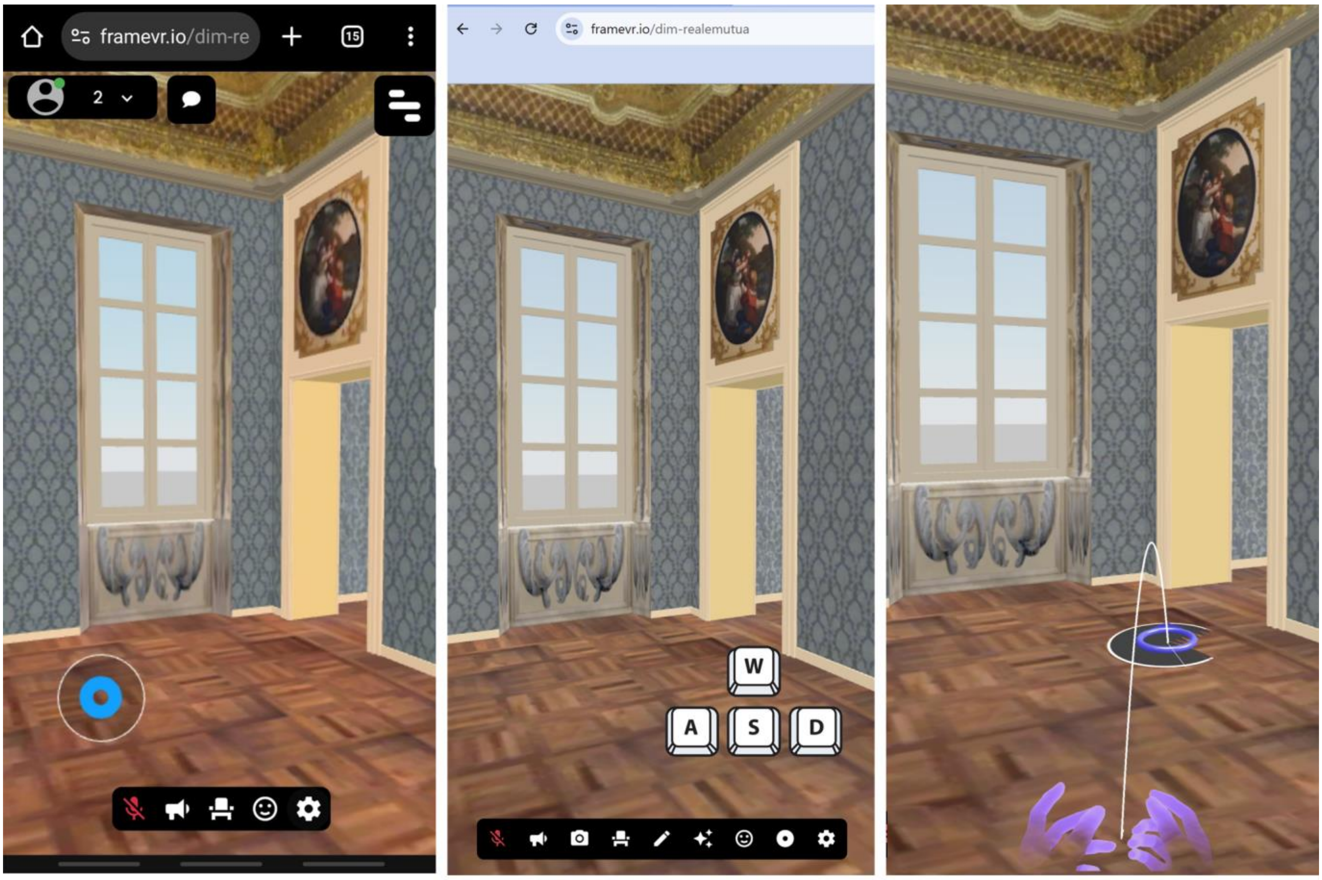
Tab. 3: Comparison of requirements for 3D digital assets stored into diverse platforms. Direct upload on FrameVR and upload specification within SketchFab Pro account (author: J. Bono).

3D assets characteristic	Requirements (max.)	
	FrameVR	SketchFab
Active faces	130’000	-
Materials	20	100 (4096x4096 px)
Format	.glb/.gltf	.fbx/.obj/.dae/.blend /.stl and others
Size	50MB	200MB*
Coordinates	(x, y, z)	(x, y, z)
Active faces	130’000	-
Materials	20	100 (4096x4096 px)

The content was identified as the 3D models corresponding to the various configurations the students developed as exhibit design proposals. Subsequently, the assets were first organised into a digital collection on SketchFab and then retrieved by creating different and alternative 3D scenes (Fig. 19).

Creating fully customisable immersive spaces facilitates communication and collaboration among multiple users within the virtual environment. The platform offers a free plan for creating SVEs, with limitations of three immersive environments (frames). Additionally, the premium version can remove restrictions on features and assets.

Although FrameVR limits access to a maximum of eight simultaneous users, It does not require registration to access the SVE platform using avatars. Metaverse and SVEs involve the creation of a 3D avatar, a distinctive feature compared to traditional 2D social interaction platforms (such as



Mobile Desktop VR Headset

Fig. 19: FrameVR developer interface showing the list of available resources (larger image) and the organisation of multiple scenes containing diverse 3D exhibit design proposals (SVE developer: J. Bono).

Zoom, Teams, Meet, or Skype), which rely solely on a webcam and video (Jeong et al., 2022).

Jeong et al. (2022) examined the use of the 3d avatar. They highlighted two main benefits: a high degree of co-presence, enhanced sense of engagement, and increased openness among more introverted users. These individuals are more likely to participate and express themselves in digital environments than in traditional physical spaces. Thanks to these factors, the virtual environment is established as a true community. This concept reflects the typical dynamics of social platforms, including social networks, forums, and blogs, which nurture a sense of belonging among users (Lee & Hwang, 2022).

Finally, the exploration of the virtual environment with an avatar can occur through three different modes, depending on the device utilised (Fig. 20).

Mobile devices: interaction occurs through a touchscreen. Movement is controlled by a button resembling a joystick (located at the bottom left), while orientation is managed by touching and scrolling to another point on the screen.

Desktop: Navigation is controlled via the keyboard (WASD keys) and the mouse for orientation view.

VR headset (Oculus Meta Quest 3): Once launched in the device's browser, the user can immerse themselves in the scene, physically navigating the space or using the teleporter function activated by the joystick (FrameVR).

These three typologies of fruition, although different in their modalities and purposes, are part of an evolving technological ecosystem, capable of enriching and transforming our relationship with the digital.

6. *Conclusions*

The 'Sale Auliche' projects explore techniques of digital representation, including augmented, virtual, and immersive reality. The identified exhibition themes, Internationality, Health, and Living Property were developed by addressing new public engagement strategies that place the user at the centre of the visitor experience.

In conclusion, the application of Extended Reality in education is becoming a valuable resource for stimulating learning processes, creating innovative solutions for public engagement, and promoting an interactive and immersive approach to cultural heritage.

Integrating augmented reality and immersive experiences enhances museum displays, overcoming traditional barriers to enjoying heritage and making the educational journey more accessible and engaging.

The Inside the Museum approach highlights a key aspect of digital transformation: the synergy between the educational experience and the needs of the museum sector, which increasingly collaborates with the work of interior designers and architects.

In this context, the design of museum spaces is no longer confined to housing artworks and exhibits; instead, it becomes an integral part of the narrative and interactive journey offered to visitors, becoming an immersive experience.

Architects and interior design professionals are invited to reconsider exhibition environments, incorporating Extended Reality (XR) technologies to craft functional and engaging spaces that spark curiosity and enhance learning.

This synergy enables the design of spaces that fulfil the needs of modern cultural enjoyment, where the educational experience merges with design to transform the museum into a laboratory of knowledge and interaction.

Immersive pathways, enhanced with digital elements, encourage narratives that embrace the company museum's history and identity. In an era where technology and design merge to transform the museum experience, the future of education and cultural communication is becoming increasingly interactive and multidimensional.

This integrated approach enhances cultural heritage and creates new public engagement strategies that combine aesthetics, functionality, and innovation, transforming the museum into a genuine dialogue between history, technology, and design.

The future of Extended Reality (XR) in education and architectural design is set for significant advancements that will reshape both fields. Developments in virtual reality (VR) technology are expected to enhance architectural design and presentation through greater realism, improved graphics, and heightened sensory feedback. The trajectory points to a future where XR not only enriches learning experiences but also transforms the fundamental ways in which architectural projects are conceived and executed. Future innovations are likely to incorporate interactive elements that enable users to modify environments in real-time and to integrate seamlessly with other technologies such as artificial intelligence (AI).

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