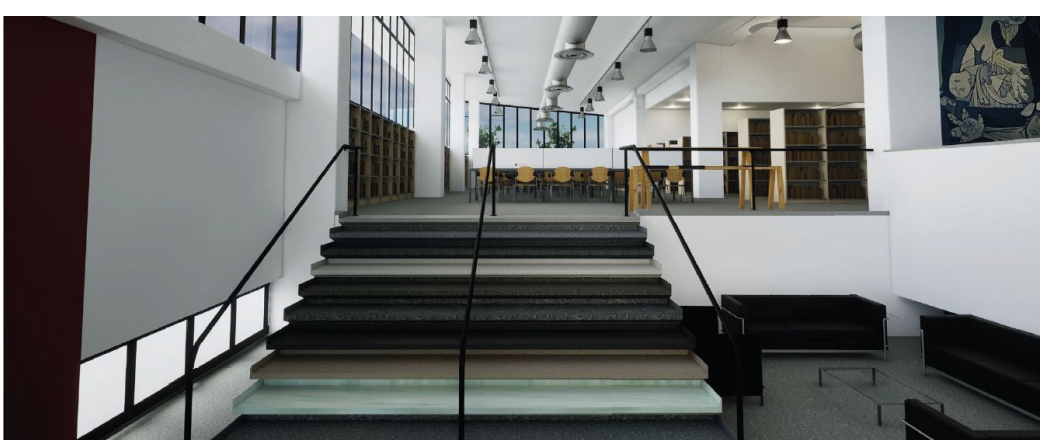
Virtual Reality-Based Digital Twins for Education

Cecilia Bolognesi
Allen Mae Baldemor
Deida Bassorizzi
Vasili Manfredi
Simone Balin

Abstract

The experimentation here described has the ambition to overtake the current state-of-the-art of virtualization by integrating and advancing innovative digital methodologies to establish a framework for library fruition empowered by accessibility and engagement of users. Furthermore the experiment incorporates the idea of virtualisation of library environments as a vehicle for global cultural engagement and accessibility to document presenting culture in immersive format that transcend physical limitations [Oje *et al.* 2025, pp. 4-5]. Focusing on the creation of an immersive environment [Maté-González *et al.* 2023, pp. 1043-1044] through a case study related to the Biblioteca Campus Leonardo (https://www.biblio.polimi.it/) at Politecnico di Milano [Ponti 1954, pp. 58-67], the research explores the whole path: from a digital survey for the creation of an accurate architectural model [Ranieri *et al.* 2023, pp. 1279-1275] to its enrichment as a digital replica accessible in immersive mode, to the enjoyment of its contained digital contents through an interactive app. The study demonstrates how VR can enhance features such as book-finding systems in libraries, reading them in virtual environment [Trizio 2019a, pp. 1174-1176; Trizio 2019b, pp. 378, 379], but not only, one of the objectives of the experiment is to test the potential of such an immersive system to evaluate the curiosity and engagement of students when faced with such a possibility. The case study involve a comprehensive digital survey and modelling process [Raco 2024, pp. 606-610], the integration of *Dewy Decimal Classification System* in the digital model of the library [Mafrici 2020, pp. 38-51] the development of a searching and reading app to be tested.

Keywords
Digital fruition, VR environment, inclusive education.



View of the application interface of the Central Architecture Library project (elaboration by the authors).

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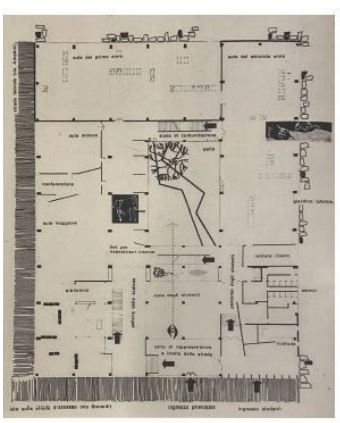
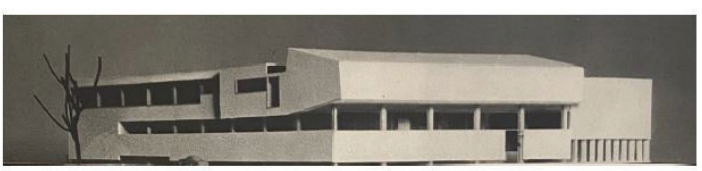
Introduction

The fourth industrial revolution, commonly referred to as Industry 4.0, is reshaping the delivery of education. A fundamental aspect of Industry 4.0 is the rapid progression of technologies within ICT (Information Communication Technology) to improve educational sustainability and productivity. This is achieved through the integration of AI (artificial intelligence), cyber-physical systems, ML (machine learning), the IoT (Internet of Things), big data, and XR (extended realities)
In contemporary education, this evolution culminates in the development of smart learning environments. Within these environments, Industry 4.0 technologies enable educators and students to optimize and personalize their educational experiences in both traditional and remote settings where VR can lead many processes. The virtual environment can be accessed by educators and students via smartphones, computer monitors, or, more recently, VR and XR hardware in the form of virtual or augmented reality. From this point of view digital technology can be considered as a cognitive partner, with collaboration tools, sharing tools, with network relations and network effects.
These technological advancements hold the potential to transform classrooms into immersive inclusive learning spaces where educational content is vividly brought to life through VR, AR or personalized learning pathways constructed using AI-driven analytics. The investigation here reported goes around the process of the creation of a virtual environment and how the integration of digital technologies with architectural spaces can affect user experiences, especially when it comes to enhancing features like the book-finding system in libraries and the reading of the book in an engaging process.

The case study

To comprehend the potential of virtual environments in architecture and the interaction of digital tools within architectural spaces, the *Biblioteca Campus Leonardo*, the central library of *Politecnico di Milano*, has been selected as the research subject. The concept with which these spaces were conceived is part of the learning experience. The construction of the faculty building housing the library commenced in 1937 under architect Portaluppi, with the idea of creating a structure featuring an internal courtyard. Later on Ponti and Forti in 1954 developed the project with the aim of "establishing the quintessential model of the School of Architecture through modern production paradigms." [1]. The space show a variety of contemporary forms, materials, and technologies of the era, allowing students to learn directly from the building itself (fig.1). The exterior facades are designed to be interpreted and distinguished according to their functions. Within the library, art is integrated through a 1:1 replica of Picasso's *Guernica* (*Museo Nacional Centro de Arte Reina Sofía*, Madrid 1937), created by the Student Movement in 1973 (fig. 2) and Giorgio de Chirico's *Hector and Andromache* painting, donated by an anonymous benefactor (fig. 3). The library holds





Corner view of the two streets

Corner view front on Via Ampère

Fig. 1 The project of the Central Architecture Library in a drawing of the time, (drawings by Gio Ponti, Piero Portaluppi, Giordano Forti).

Fig. 2 The Guernica mural created by students inside the library.

Fig. 3 *Hector and Andromache*, Giorgio De Chirico, housed in the library.

approximately 200,000 volumes, along with periodicals, funds, and dissertation collections, making it one of the largest scientific libraries in Italy. This valuable resource could be shared for the benefit of the scientific community and this is the purpose of this project. focusing not only on digital duplication of contents but also of spaces, considered as a part of the cultural engagement.

Cataloguing

The cataloguing system is a fundamental part of the digitization and development of the app. The library uses the *Dewey Decimal Classification System* (DDC), developed in 1876 by Melvil Dewy, offering a series of advantages as flexibility. The system provides a classification of books or material to a series of categories. If one book has one or more topics, it would cover all of them and would be able to be searched from each one of them. The system is divided into three summaries. The structure has ten main classes, divided into ten divisions divided into ten sections. Decimal points and letters are also used. The decimal points make the division for the subsections clearer while the letters are used mainly to indicate the author. Usually for the initials five letters are used: four are taken from the surname and the last

one is the name. Numbers could come after letters, and these would indicate the volume of the book. An information needed to start the process of book finding is the specific DDC coding of each shelf and each level of the shelf. To match codes and shelf levels easier, the shelf levels are scanned in a way where the top shelves are named alphabetically from 'A' arriving to 'D' for four level shelves and 'E' for five level ones (fig. 4).

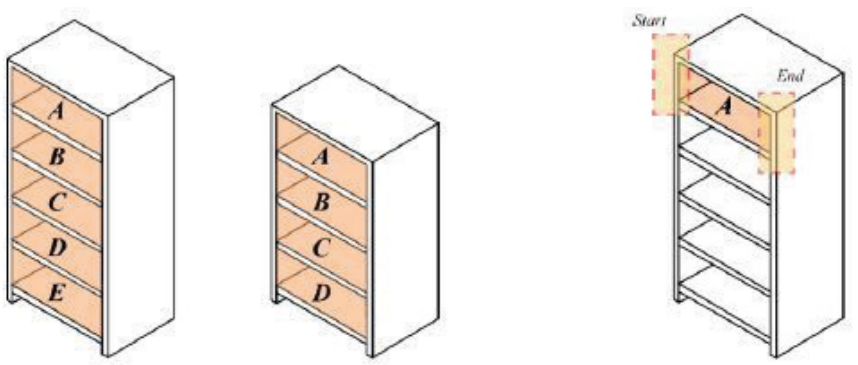


Fig. 4 Code derivation method in relation to shelving. (elaboration by the authors).

The digital survey, the modelling, the rendering

To create the digital replica model of the library, a laser scanner survey was conducted using a *BLK2GO* mobile laser scanner giving as a result two point clouds. This covered both the interior, focusing on the open shelf area, and partially overlapping the exterior. The portable imaging laser scanner features a relative accuracy of 6-15 mm and an absolute indoor positioning accuracy of 20 mm. It can visualize in 360° horizontally and 270° vertically. The scanner requires *Leica Cyclone Register 360* and *Cyclone Register 360* (BLK Edition) software for registering the scans.
The software processes the two point cloud data, forming the basis of the model and allowing the creation of a single bundle sum of the two clouds, resulting in a point cloud comprising approximately 120 million points for subsequent modelling. The maximum error achieved was 0.002 m, as calculated by the software. Concurrently, a photogrammetric survey of the stones used in the project and the Guernica mural was carried out using a Canon EON6D. Existing photographic reproductions were employed for De Chirico's canvas. The final step involved exporting the model. Although .e57 format files are needed for direct use in Blender, many errors led to choosing the .rcp file format for import into *Cloud Compare* v2.13.1. Files were then exported through *Cloud Compare* in suitable formats. The .PLY format provided the best performance and was ultimately selected. During the modelling phase, *Blender* version 4.1 was chosen due to its open-source nature and efficient interface for producing virtual models and texturing surfaces. The virtual model was created with the point cloud as a reference. Except for the external trees and metahumans, all parts of the model, such as chairs, lights, and shelves, were modelled from scratch, enhancing attention to visual detail such as textures and lights (fig. 5). To achieve an efficient UV map, unwrapping via seams or smart UV projection is necessary. The UV map dictates how and where the texturing application occurs on the model. Textures were applied using the *Principled BSDF* node, which combines multiple layers into a single node. *Quixel Megascans*, a comprehensive library that provides scans ranging from surfaces to 3D assets and *Metahumans*, was utilized to importe texture to the mesh. As not all required materials are available in the library specific marbles of didactic importance missing from the floor were produced using the *Materialize* software (fig. 6).
Photographs of the objects were imported, adjusted as needed, and used to generate diffuse, metallic, height, roughness, or normal maps in various formats like .jpg and .png. This

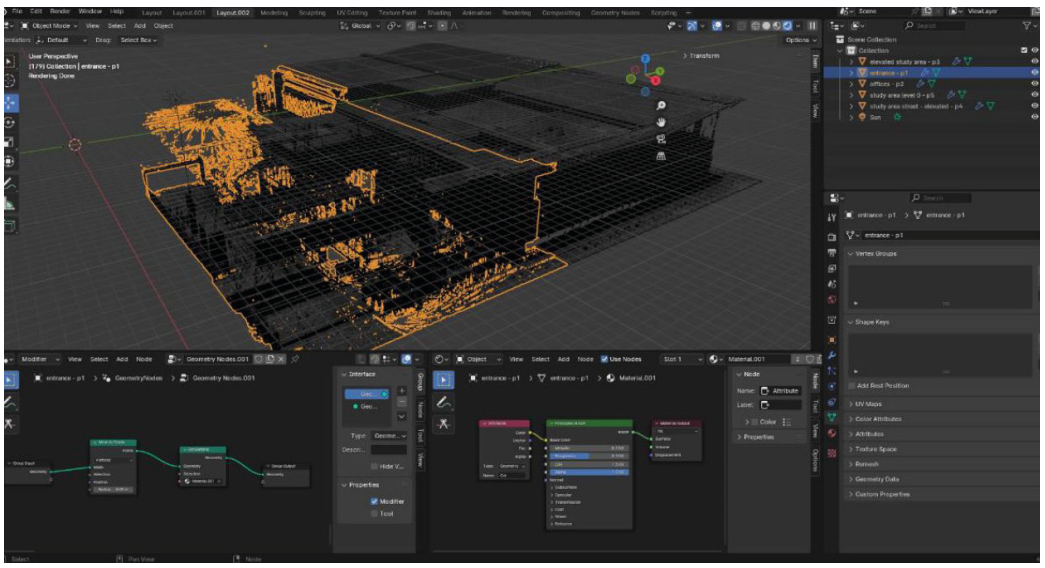


Fig. 5. Importing .ply files into Blender (screenshot by the authors).

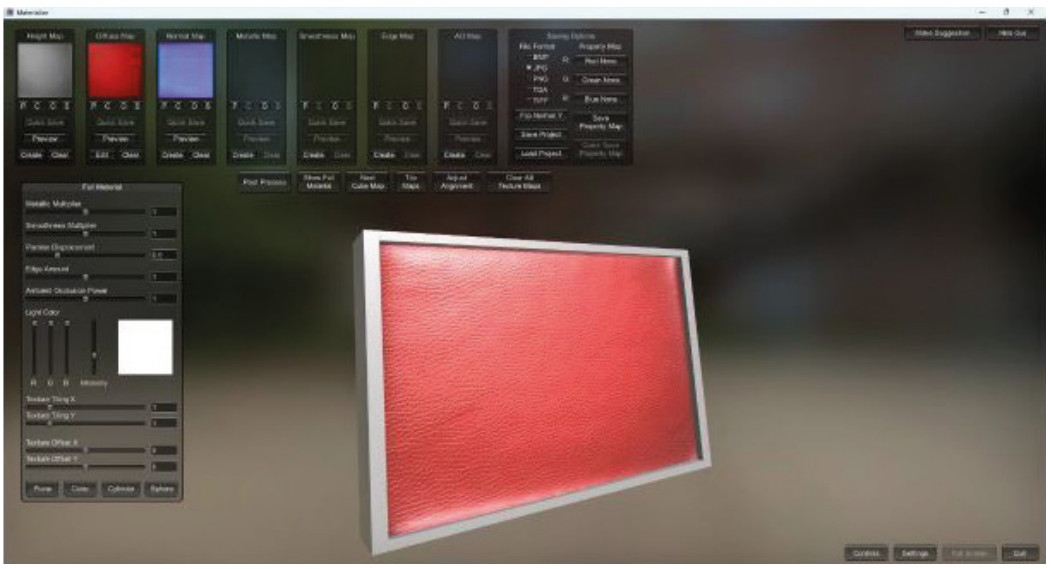


Fig. 6. Creating textures in Materialize (screenshot by the authors).

method was employed to obtain the missing marble textures and exterior facade tiles (fig. 7). Emissive textures were applied to objects requiring light emission. These assets serve as a foundation for *Unreal Engine* but may require further adjustments such as proper orientation of normal that is crucial to avoid issues when importing to *Unreal Engine*, and the file is ultimately exported in the .fbx format.

A notable disadvantage encountered was the potential need to relink materials and objects. *Unreal Engine* 5.3.1 serves as the rendering system. Illumination settings are meticulously checked and adjusted, particularly in darker areas where additional lighting is necessary. Rendering issues in certain spaces are addressed based on the rendered frames' output. To commence rendering in *Unreal Engine*, cameras must be positioned within the 3D model according to the desired framing. Various settings can be tweaked to achieve the preferred outcome before queuing the render process (fig. 8). Many issues occurred in *Unreal* workflow, among them: missing faces and objects, faces not visible when navigating, objects with error inside. The solution were foud as listed in order: the problem was inside Blender, normals should all be recalculated and flipped for the objects that want to be seen; the objects had no extrusions in *Blender,* they had to be extruded in *Blender* and for the normals to then be

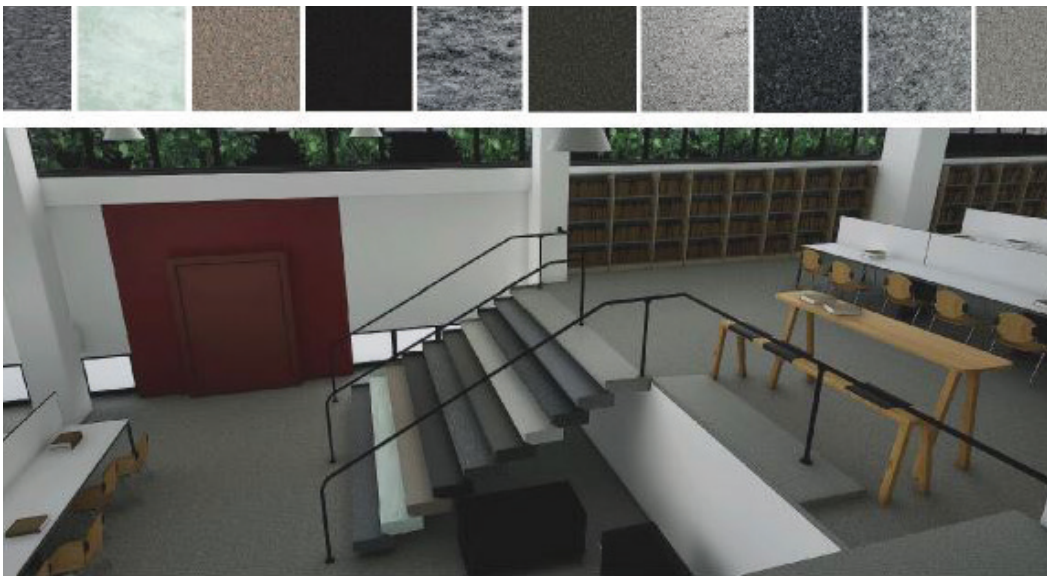


Fig. 7. Stair Marble Material Palette (screenshot by the authors).

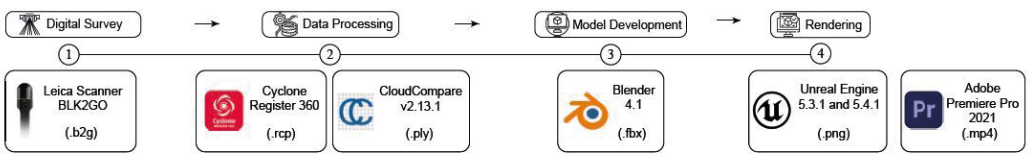


Fig. 8. A complete workflow from the survey to the digital model before the App.

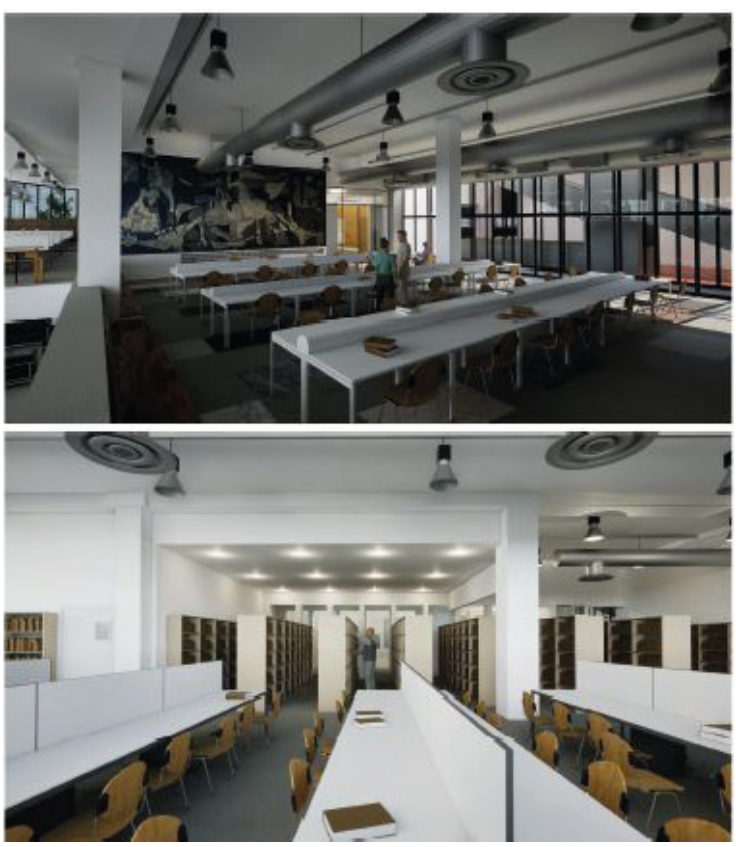


Fig. 9. Two views of the interior, with the completed render (screenshot by the authors).

recalculated; objects still missing after normal adjustment; some objects are understood to have an error inside *Unreal Engine* due to the mirroring in *Blender,* UE5 then reads them as flipped surfaces having flipped normals, therefore, they had to be recalculated, some are also parented to different layers, thus, these 'parenting' had to be removed (fig. 9).

Virtual fruition

A booklist database is primarily utilized for the book finding algorithm, serving as the repository for DDC codes. The names and corresponding codes are stored in an 'array variable,' which permits multiple values for the same variable based on an index. This setup allows for two arrays: one for the name and another for the code. Each array shares the same index, facilitating easier identification of the book's code alongside its name. Codes adhere to a specific format: the first section is exclusively numerical, the second contains only letters, while the third and fourth sections may be numerical, alphabetical, or absent. Utilizing this system, the book's code can be compared with the last book on each shelf. As books are arranged in alphabetical and ascending order, this comparison begins with the first shelf and proceeds sequentially until the desired book is located.

Upon ensuring the functionality of the system, a problem arose concerning the integration of the codes into an already large file, causing the application to lag. To address this, optimization was necessary. One strategy involved initially comparing the last book of each section before narrowing down to the appropriate one, thereby reducing the workload by one-third. Subsequently, comparing the last book on each shelf before focusing on specific shelf levels further reduced the workload by a factor of five. These optimizations resulted in a 15-fold increase in calculation speed, restoring the application's fluid performance. *NavMesh* technology along with a *Spline Property* are used to do the *Path Finder.* This technology is usually used by AI-controlled characters to navigate a 3D environment. For this, it is used to obtain the path calculation. *NavMeshBoundsVolume* is created and added to the level and with this, *Unreal Engine 5* automatically computes the walkable surface for a pawn and traces paths across. The *NavMesh* is a collection of polygons that are usually triangles that cover walkable areas. These polygons are connected, forming a network of navigation nodes. Each of these represents a specific location in the world and each polygon is a walkable surface between these nodes. The AI character traces its movement by navigating from one node to another, across the *NavMesh* (fig. 10).

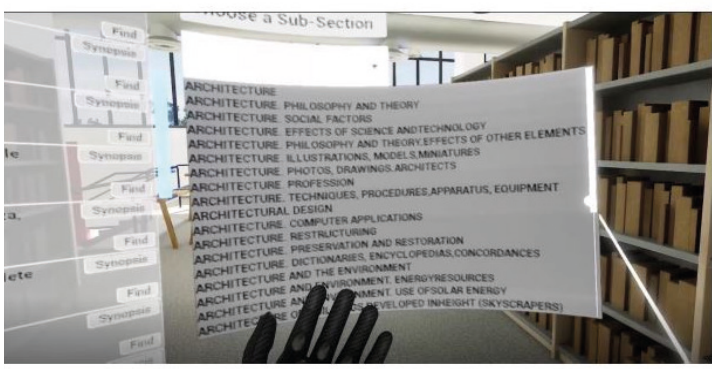
The engine begins by determining which polygon or triangle the AI character is currently standing on (starting point) and which polygon contains the target location (end point). Vectors would then be traced between the nodes, within the *NavMesh*, forming a sequence of movements. The system then computes a path that connects multiple waypoints, which are intermediate positions the character needs to pass through to reach the destination (fig. 11).

Fig. 10. Virtual tour.

Virtual interaction through the app

The VR Headset Application developed permits an interaction inside the virtual environment modelled with the use of VR headset and controllers. The video demo shows the possibilities the app gives, accurately finding the specific location of the book that is searching, finding and grabbing it, opening and reading.
After a tutorial on how the VR controller should be used a menu tab can be opened providing two options as to how people would want to find the book: 'type to search', or 'browse your categories'. In the first one you add the title of the book or the author, where options could also be found when typing names (fig. 11). When browsing, you find that some contents are inside certain keywords or categories (fig.12). These categories are organised in classes, divisions and sections, just as the DDC system method is catalogued. Sub-sections are also provided on some sections due to the wide range of books it has. In the virtual experience when a book is chosen, an orange path virtually leading to the book would be seen. The level of the shelf where the book is located is also highlighted in red, then the book can also be grabbed and opened. The possibility of opening a document and read inside the VR experience is provided. A protected document entitled *Trattato Teorico e Pratico dell'arte di edificare* by Rondelet, provided by the library can be read in the app demo (fig.11). The *Trattato Teorico e Pratico dell'arte di edificare* is a protected document. The provided access for this was only for a decided period and sending this document does not mean it could be read by whom received it. With these types of files, this application also guarantees its security not to spread (fig. 12).
In the virual environment, the virtual library can be navigated in walkthroughs and flythroughs inside *Unreal Engine* 5, offering the programs high quality graphics. By connecting the VR headset to UE5, it is also possible to navigate and test the application made. As a secondary product for communication purposes, a 360° video tour of the virtual library can also be seen in the VR headset.

'Browse your categories' Option



'Sub-sections' Option

Fig. 11. Views of the application interface (screenshot by the authors).

Fig. 12. Application demo.

Conclusion

This experience has allowed us to solve many problems related to the fruition of virtualized spaces and cultural content present in this case in our university. The technical problems of the experimentation have been addressed and resolved, but some remain. Tey relates to hardware issues such as the memory of standalone devices or, in parallel, the weight of some materials rendered in photorealistic mode, the detachment of textures from objects, and the mobility of tests handled with controllers.
Even the digitization of volumes is a topic to reflect on. The association of the cover image with the volume, a theme of cultural recognizability, can be easily resolved while the portability of visualization tools throughout the reading is certainly still to be resolved. Meanwhile, the possibility of digitizing cultural content in their own environments of fruition broadens the experience, favoring the recognizability of the cultural identity of a place despite the multiplicity of contents.
However, the experiment, which can be improved, can be regarded as a significant step on the path of inclusivity, towards both disadvantaged categories and countries lacking excellent scientific structures.
Furthermore, it can mark yet another step in the creation of virtual environments replacing large territorial transformations, substituting vast physical spaces with immersive experiences that can be enjoyed both individually and collectively, not only with multiple devices but also in specific small-sized immersive rooms.

Note

[1] Facoltà di architettura del Politecnico di Milano - Milano (MI) | Architettura in Lombardia dal 1945 ad oggi. (n.d.) https://www.lombardiabeniculturali.it/architetture900/schede/p4010-00331/.

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Authors
Cecilia Maria Bolognesi, Politecnico di Milano, cecilia.bolognesi@polimi.it
Allen Mae Baldemor, Politecnico di Milano, allenmae.baldemor@mail.polimi.it
Deida Bassorizzi, Politecnico di Milano, deida.bassorizzi@polimi.it
Vasili Man*fredi,* Politecnico di Milano, vasili.manfredi@polimi.it
Simone Balin, Politecnico di Milano, simone.balin@polimi.it

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