Virtual library in the concept of digital twin

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***Abstract*—With the technological advancements and the widespread adoption of the internet, the physical library has lost its role as the main resource of information. As the Metaverse is becoming more and more apparent, a revolutionary change is expected in how we understand social relationships and consequently, education. It is therefore necessary for libraries to upgrade the services they provide to keep in line with the technological trends and be a part of this virtual revolution. We believe that the design and development of a Virtual Reality (VR) library can be the community and knowledge hub the society needs. In this paper we go through the process of creating a digital twin of the Limassol Municipal University Library, a landmark for the city of Limassol, by using photogrammetry and 3D modelling. By integrating the concept of digital twin, we developed a 3D platform where users have the perception that they are exhibiting the actual library. To do so, we conducted a perceptual study to understand the current usage of physical libraries, examine the users' experience in VR, and identify the requirements and expectations in the development of a virtual library counterpart. Following the suggestions and observations of our user study, we implemented five common case scenarios that demonstrate a potential use of a virtual library.**

***Index Terms*—Virtual Library, Digital libraries and archives, Metaverse, Virtual Reality, Digital Twin.**

I. Introduction

Though we have evidence that libraries have been to existence as early as the 7^{th} century BC, as per the example of the Ashurbanipal Library [8], it is only recently that the physical library lost its role as the main resource of information [1]. The invention of the internet revolutionized the way we can access and distribute information. Libraries are adapting and are using digital technologies in order to continue being a hub of structured information, but the lack of an actual place that users can meet makes it challenging to keep their role as a community hub, or a place of social interaction [24]. Already, a number of immersive educational tools are available, and libraries should begin investigating Virtual Reality platforms for their services. The main objective is to develop services that are both user centered and digitally inflected. A virtual library needs to be a community hub, a space that is persistent and dynamic where people can meet to collaborate, discuss and exchange ideas and information.

Virtual Reality (VR) is an emerging technology that allows people to experience artificial worlds with an extreme level of immersion [6]. Recent advancements in the technology field have introduced more-realistic and enhanced experiences; the substantial improvements of the VR headsets allow people to visualize 3D scenes with remarkable clarity and realism. VR systems have become more accessible over the last decade due to the much lower cost, the massive advances in graphics, and the exponential increase in computing power [31]. Indeed, these systems are now cost-affordable to a wider range of entities and people, including home users, elementary and high school students. The exposure of VR technology through movies, television, or the internet means that members of the public at large are becoming aware of it. As the technology advances, it is a necessity for libraries to be upgraded and thus being member of this virtual revolution. More and more people, especially the youngest generations, are becoming familiar with VR applications, while there already exist educational applications that use the benefits of virtual environments [18]. Libraries should therefore upgrade their provided services, within the framework of virtual world, so as to be in line with the current technological trends. As the Metaverse - a post-reality universe, a perpetual and persistent multi-user environment merging physical reality with digital virtuality [25] - is becoming more and more apparent, a revolutionary change is expected in how we understand education and social relationships. Developing educational tools offers tremendous learning benefits to people with moving or other disabilities, compared to more traditional methods. We believe that, the design and development of a VR library in the Metaverse can be the community hub that the society needs.

The first step in any virtual environment is the design and development of a virtual platform, where users can connect and interact with through a Graphical User Interface (GUI) or a virtual agent. Given that many libraries are deeply connected with the architectural history of the building they are hosted in, the use of a digital twin helps with the preservation of the building, and allows the user to perceptually feel that they are navigating inside the actual library. The first formal definition about *digital twins* was given by Michael Grieves [16], that is described as a digital version of a pre-existing or planned physical object. It has been shown that digital replications of physical entities enable data to be seamlessly transmitted from physical to virtual worlds. Digital twins facilitate the means to monitor, understand and optimize the functions of all physical entities and provide people continuous feedback to improve

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quality of life and well-being [12].

In this work, we investigate the needs and expectations of library users in the development of a virtual library, in our case the Limassol Municipal University Library (a Cultural Heritage protected building), and propose the development of an immersive VR platform, in the broader perspective of digital twins within the Metaverse. In particular, we conducted a perceptual study ($n = 70$) to study and understand the reasons why people are visiting or not a physical library, how often they access library resources physically or through a library webpage, and how satisfied they are with a number of given library services. Our perceptual survey also examines the user's experience in VR, and their requirements and expectations in the development and design of a virtual counterpart. We aimed at sketching the profile of a potential VR library user (e.g., their experience in VR, their background etc.), while our ultimate target is to set the foundations for the design and development of VR libraries in the future. We documented a number of suggested services which users believe are essential in virtual libraries, and implemented a virtual equivalent to a library, demonstrating five case scenarios: a virtual tour of the library; lending books; attending a seminar; booking and exclusively using a virtual study/meeting room; and booking and virtually meeting a mentor/subject specialist/librarian. In that manner, library users can explore the emerging technology and observe its potential usage as an educational tool. Library should be an organization that pioneers in the usage of emerging technology, and more specifically the usage of VR when providing their services, for the user experience to be as high-quality and as impactful as possible.

Our work paves the way for the 3D virtualization of libraries, showing the impact VR can have in the resurrection of libraries as social hubs; this has been achieved through the process of accurate digital reconstruction of the building. We aim to assist libraries to follow the technology trends, attract the interest of younger generations, and preserve their characteristics in the digital era. Understanding the potential users of the virtual library and identifying the scenarios the library could be used can offer substantial assistance both to researchers in the Virtual Reality domain, as well as libraries to upgrade their services.

II. Related Work

This section discusses the literature review, in the general scope of the reconstruction of virtual libraries as digital twins, and their educational and learning aspects that is associated to the concept of virtual museums. The related work is divided into three main sections: (a) 3D reconstructions and the definition of digital twins; (b) educational tools and virtual museums; where in (c), we focus more to our case study, the virtual libraries.

A. 3D reconstruction and digital twins

The 3D acquisition or reconstruction of any cultural heritage space (in our case, the Pilavakis Mansion where the library is located) or artifact allows for the creation of virtual spaces, accessible from any location at any time [39]. The installation of a virtual environment (e.g., museum) can exist in the physical space, or only virtually where it can be accessed remotely. Since the proposition of Virtual Reality Modeling Language (VRML) by Raggett in 1994 [28] the amount of probable uses of 3D virtual environments has been constantly increasing. One of the first internet based VR exhibition system (VRES) was proposed by Su *et al.* [33] and was based on the VRML technology. In more recent years, Vosinakis *et al.* [36] presented an excellent example on how a virtual and a physical environment co-exist, one completing each other. In a similar aspect, our implementation of a virtual library can have a direct association with the physical library, without subtracting from the experience of visiting the physical library. In order to achieve this goal, we have created a 3D virtual library that can be used as an educational tool for the user, and at the same time a virtual museum of the building itself, in the general concept of digital twin.

Digital twins have not been popular in the Cultural Heritage field; however, research around it and related technologies could improve the virtual authentic representation of heritage or other landmark assets [26]. The digital twin concept is to have a continuous connection between the physical asset and its digital copy, which is vital in the production industry. The case of the digital twin of an underground oil-mil in the town of Gallipoli (Puglia, Italy) [13] presents an example of how this technology could be used in Cultural Heritage, where a shared virtual visit to an inaccessible context is presented. However, in this example, the connection between the physical and digital objects is static, rather than dynamic, as it is in most cases in digital heritage and virtual archaeology. Such connection is critical for the integration of digital twins, but it is usually lost due to external factors, such as the location of the physical asset, e.g., in restricted conflict areas [29], or the alternation or destruction of the original asset [5].In our case, we have faithfully reconstructed the library within the concept of digital twins; since the aforementioned factors do not stand in our case, we hope that this connection link between physical and virtual assets will remain active.

B. Educational tools and virtual museums

Organized collections are dated as far as 530 BC, e.g., the Ennigaldi-Nanna's museum in Ur, devoted to Mesopotamian antiquities [23]. The word museum originates from classical times when "mouseion" meant "seat of the Muses", a place to admire and think, to get inspired. In the Roman times, its derivation was limited to a place of philosophical discussions, like the great Museum at Alexandria. In the 18th century, the word museum evolved to mean a building were cultural material were kept to which the public had access. Multiple definitions of the museum include the terms enjoyment and education or learning[1], often described in one word: *edutainment*, that is to be entertained through learning. Researches in psychology and cognitive sciences have shown that memories

[1]http://icom.museum/en/resources/standards-guidelines/museum-definition

and thus learning is reinforced by emotions [9], [17], [32]. Today, a number of different types of virtual museums exist, either as online applications or 3D environments, exhibiting both tangible and intangible artifacts, with their scope being educational, edutainment, enhancement of visitor experience, promotion and research [3], [34], [38]. However, in most of the online virtual museums, the interaction between the user and other virtual objects is limited mainly due to the restrictions on the input devices (e.g., mouse, keyboard, touchscreen); it is therefore suggested to design VR applications that allow users to naturally interact with the environment. More recent approaches recommend to develop virtual environments that are not restricted by a specific form of pre-structured story given by a curator, but let the visitors to define the scenario and create the exhibition experience based on their interest and needs [22]. Indeed, we cannot simply impose pre-selected narratives to the visitors and expect a consistent response [20]. Each individual user should have their own experiential perception that is based on their level of understanding. In addition, a series of projects showed that VR applications create digital involvement by active participation, and enhance learning through a cognitive dialogue with the user [30], [34]. VR has indeed the potential to revolutionize education and museum/library exhibition; with education as a whole shifting to more online settings, VR could be a groundbreaking addition to any lesson plan since it makes learning fun, safe, and more engaging than ever before. In that manner, we have designed and developed a VR environment to enhance the library experience, while improving the user's immersion and engagement via an enjoyable and safe setting.

C. 3D Virtual Library

The library is considered to be a hub for social interaction and knowledge dissemination in a community. In a similar way, a virtual library should maintain the role of the physical library, as well as its main goals, values, and visions. Many researchers were interested in the ways VR can be used to improve the library experience [15]; however, currently, only very few libraries have fully switched to a virtual counterpart. Massis [24] in his paper shows that VR/AR provide valid additions to the tools used by libraries for the users' engagement, while also discusses that through the use of VR/AR students are provided with more means to practice their information literacy skills, and learn to use every tool in their arsenal to enhance their education experience.

One of the first 3D virtual libraries was build to evaluate the behavior of users when searching for a book in VR [10]. The authors discussed the idea of conducting the experiments in a virtual setting that follows the arrangement of the physical library, and repeated the same tests in both physical and digital environments. They observed several particularities with regard to the position or spatial arrangement of the library that influence the user behavior and should be taken into consideration on the initial design. Other implementations of a 3D virtual library include the ancient library of Alexandria [4]; the Oulu City Library [19], that is operated in parallel within the physical library premises; or the National Library of the University of Debrecen (UNLUD) [14]. A virtual library can also be used as an educational tool through Presense Pedagogy. In such a setting, teaching and learning is grounded in social constructivism [7], where all users can benefit from others expertise. A closer example to the digital twin concept was presented by Pouke *et al.* [27], where the digital part of the library was enhanced with imaginary fantasy layers. Their qualitative user evaluation showed that this kind of a VR experience is an exciting extension to a physical library, suggesting that VR can offer unlimited experiences. In a similar way, we have developed a digital twin of the Limassol Municipal University library that enhances immersiveness in creating knowledge through the VR technology. Our work is based on the outcomes of a perceptual study that was conducted to sketch the profile of a potential VR library user, aiming to understand its expectations and challenges.

III. Perceptual Study

As the physical library is at a critical phase of its lifeline, where its identity is questioned due to the digital revolution, we need to understand the current use of the physical library, its limitations and challenges that keep away potential visitors, the challenges that are emerging, and what possibilities and opportunities technology can offer. In that direction, we conducted a perceptual study through an online questionnaire; the sample size was 79, with 9 incomplete responses, leading to 70 valid responses. The participants consisted of 45 males and 25 females from various educational backgrounds (6% high school graduates, 4% college graduates, 46% University graduates, 26% with a postgraduate degree, and 19% with a Doctorate degree) and specialization (7% Life Sciences, 21% Social Sciences & Humanities, 57% Physical Sciences & Engineering, 14% unknown) with current situation being mostly employed (61% Employed, 36% Students, 1% on maternity leave, 1% Unemployed).

The study revealed that the majority of the participants (70%) visit the library rarely or not at all, while the remaining 30% goes to the library once a month or more. People from the Humanities Studies are those that more likely visit the library, followed by the Natural Sciences & Engineering, and finally the Social Studies. From the frequent library visitors, only one third of them is a daily visitor (approximately 7% of the total survey population). This divulge that people are no longer engaged in physical libraries as their main source of information and knowledge. On the other side, the website is an essential asset for a library as 53% of the participants use the library's website monthly or more frequently, which shows that people are converting to using modern technology or accessing the library's contents online, especially from the convenience of their home or office. Among the reasons that mostly inflict friction in the process of going to the library is the fast pace of life and the lack of available time, the location of the library which is considered to be not close to the participants' place of stay, or impractical because of the scarcity of parking places around the library.

Most people who use the library frequently are students, who visit it either for reading or for rest between classes, and one of the most common problems reported is the noise of the surrounding people and/or printer machines that interrupt their focus and concentration. This also shows the social aspect of the library, as people are meeting for their social interaction when resting between classes. On a multiple answer question, where participants could vote for one or more answers, our study revealed that 69% of the physical library visitors use the library services mainly for studying, 40% for work related reasons (e.g., read academic articles), and 13% for other reasons (e.g., leisure).

In general, the participants are mostly satisfied with the provided library services: in particular, on a 5-likert scale, 70% of the library visitors reported that are either satisfied or very satisfied with the lending services (25% neutral, 5% unsatisfied), 47% with the copying services (41% neutral, 12% unsatisfied), 68% with the access and speed of the internet and the library internet service (23% neutral, 9% unsatisfied), 68% with the information and research services (24% neutral, 8% unsatisfied), and 43% with the cultural and educational programs organized by the library (40% neutral, 17% unsatisfied).

However, it seems that not all the participants are aware of all the library provided services. For instance, 72% of the frequent visitors indeed knew that they can attend a tour within the premises of the library that briefly explains its services, while only 34% of the non frequent visitors are aware of this service. Similarly, 76% of the frequent visitors knew that they can attend specialized lectures and seminars in the library, but only half of the non frequent visitors. Other services, such as "Get assistance or meet a mentor/subject specialist/librarian", book an "exhibition space to organize an event", or "borrowing books from other libraries" score low in both the frequent (56%) and non frequent visitors (34%). This shows indications that most people who are not regular visitors are also not aware of many of the available services that might be interested to use. This highlights the need to design a GUI menu, in the digital form of the library, that displays the offered services, from which the user can select between many. It is important to note that, in the question "What service could the library offer to make it better?", a number of participants suggested to have more online services (e.g., book or room reservations), virtual environments, better printing services, help desk services, and more socializing spaces (e.g., lounge rooms and restaurants).

In this survey, we also aimed at understanding the technological background of the participants, and sketch the profile of a potential user of the VR library. The ultimate target is to assess the potential utility / popularity of visiting and using a virtual library. The 22% of the participants claim to be regular users or experts with VR technology, 45% have used VR only once, and 33% have never used VR. However, none of the participants actually own a VR headset, 85% do not have direct access to a VR headset, while only 15% have access to it (mainly those coming from the Physical Sciences & Engineering field). This proves that using this technology

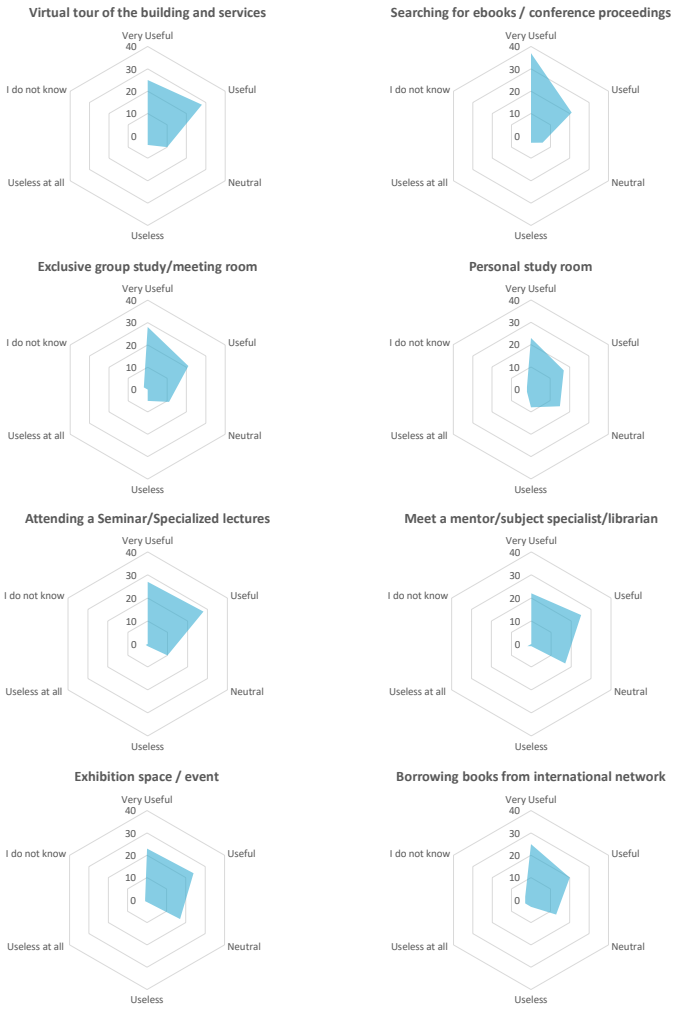

Fig. 1. What services would be useful in a VR library?

is still at an early stage in the general population - it also shows the need to modernize schools and academic institutions that should provide access to such immersive technologies. We believe that prices will further fall, as is the case with all technological gadgets, thus headsets will be available to a wider population; such a device is expected to be an integral part of our daily lives. Note that only half of our participants were aware of or being familiar with the concept of Metaverse (e.g., the new technological VR innovations). The participants' friction with a VR service (e.g., virtual museums) shows that there exists a motivation of using such services as the 45% of the participants have navigated VR environments in the past, and 66% shows an avid interest to visit and explore a virtual library, plus 23% out of curiosity, as a part of a virtual world/environment (e.g., in the Metaverse platform). The main reasoning for visiting a VR library was reported to be the convenience of use from home, the quiet environment which offers greater concentration, the ease of access, the lack of available time to visit a physical library, the motivation to try new and innovative technologies, and of course curiosity.

We further investigated on what services would be useful in

such a VR library. The responses were in order of preference the following: (1) content search with 86% preference; (2) attending seminars/lectures with 82%; (3) a virtual tour in the library with 79%; (4) using a shared study/meeting room with 73%; (5) receive mentor/specialist assistance with 70%; (6) book and use a space for an exhibition/event with 70%; (7) borrowing books from the library's international network with 67%; and (8) book a personal study room with 59%. As expected the content and its accessibility is the most anticipated service, followed by the educational and social services, making the VR library a hub where you can study and learn from books, but also meet and interact with other people. Figure 1 illustrates the responses of the participants on a 5-Likert scare in the question "What services would be useful in a VR library?". Based on these observations, we structured our virtual library implementation, developing five case scenarios that users can use in a VR environment. Other suggested services include: the ability to read virtual books and explore them as 3D models (watch accompanying animations/ movie clips), customization (making font bigger/ fancier,enlarge an image of the book, etc), social meetings, tools for disabled people, taking notes and personal dashboards etc. Regarding on what characteristics would make the VR library more attractive, the responses were in order of preference the following: (1) visual fidelity with 86%; (2) VR experience with 83%; (3) gamification with 81%; and (4) social interaction with 61%. It can be observed that VR libraries will become more attractive when applications with an immediate impression on the users, such as immersion and the visual fidelity are integrated into the system, while other characteristics that need time to be appreciated, come second.

Other interesting suggestions form the survey participants were to have holograms of the authors explaining their work, virtual storytelling with "jumping" into the world of the book, virtual parties, combinations of virtual and augmented reality and mainly characteristics that would not be possible outside a VR environment. Arguably, an extraordinary experience of that kind would be a unique opportunity to attract more library users and retain them for longer. Nevertheless, the need of further peripheral resources make the use of such applications difficult for the time being to proceed with such implementation.

IV. 3D Reconstruction

The Library of the Limassol Municipality was initially housed in the main hall of the Municipal Mansion and was opened for the people in October 1945. Later in the early 1970s, the library moved to the Pilavakis Mansion[2], because of the limited space in the municipal hall and the needs for a modernized library that will satisfy the needs of the citizens. The construction of the Pilavakis Mansion, which currently is a trademark for the city of Limassol and a point of reference for its citizens, began in 1919 and was passed to the ownership of the municipality in 1966. The style and decoration of this building was the result of the ambition of Antonis Pilavakis, who wanted a house to resemble the architecture of a casino in Monaco [2]. Early attempts to digitize the Municipal University Library, for its digital preservation and online visit, have only been achieved in the concept of 360 virtual tour and maps - an interactive 3D walk-through with printable floorplans, annotations and embedded media, with aerial and ground showcases[3]. However, these visualizations only allow users to visit and walk-through the building, without having access or the possibility to use any of the library's services.

Fig. 2. Sparse Point Cloud of the Pilavakis Mansion

In this work, under the concept of digital twins, we create the 3D counterpart of the library in order to allow its integration to 3D virtual platforms, such as the Metaverse. For the 3D reconstruction of the building, two different methods were used: the *exterior* of the building was reconstructed using the Structure From Motion (SfM) method, known as photogrammetry; this is a digitization process for the 3D data acquisition of physical objects and buildings, mainly used in cultural heritage, which also includes texture information. The 3D location of the points on an object's digital surface are computed based on overlapping images with camera position and orientation information known as exterior orientation [35], [37]. On the other hand, the *interior* of the building was accurately modelled in Unity3D (package ProBuilder, progrids) based on the architectural drawings and images captured on the spot. It is important to note that any photogrammetry attempt for the interior was extremely difficult as there are many loose objects in the library, and we only had limited resources restricting us for an accurate reconstruction.

For the reconstruction of the exterior part of the building, the process is divided into three stages. The first stage of SfM is the recording, e.g., taking the pictures. We captured 1305 photos, taken from a mobile phone's camera (OnePlus 3T) for the ground level details, and a drone (DJI Mavic2 Pro) for the higher level and roof features. The photos were then processed using the "Reality Capture" software that offers high levels of quality while being fast and easy [21]. The next step in the SfM workflow is the images' alignment. The relative position of the cameras with respect to the scanned asset was computed and a sparse preview point cloud was created (see Figure 2).

[2]https://www.limassolmunicipal.com.cy/en/library

[3]https://my.matterport.com/show/?m=GgWGrgEfKL8

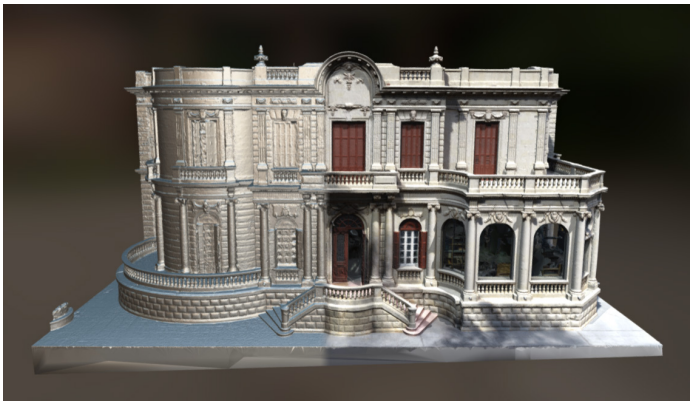

Fig. 3. Untextured and textured of the 3D model, as illustrated in SketchFab.

Following the process of creating the sparse point clouds, the last step is the creation of a detail mesh of the asset, and the corresponding texture map. It is highly advised to clean up and reduce the size of the mesh resolution before creating the UV and texture map to avoid high computational cost in time and huge data files. This is more apparent when creating assets for VR where the content needs to be as efficient as possible to achieve high performance [11].

In this work, we proceeded with the reconstruction of the 3D model, optimizing and texturing, as seen in Figure 3. On the left side the mesh is presented without any color information and on the right when the texture map has been applied. More details about photogrammetry and the procedure of 3D building reconstruction can be found in Özyeşil *et al.* [39].

V. Implementation and Use Cases

A virtual library is a digital entity that offers online services in order to complement, enhance, or augment the library experience through personalization, interactivity, and richness of content, in the general concept of Metaverse. One of the main deliverables of this work is the production of such a virtual library and services, using the actual 3D reconstructed model (digital twin) of the Pilavakis mansion. Following the suggestions and observations of our user study, we have implemented five case scenarios that demonstrate a potential use of a virtual library. Our scene is completed with a number of digital assets, such as trees, lamps and other decorative elements, aiming to create a welcoming and user-friendly environment. Figure 4 top illustrates the initial scene of our implementation, where the user begins its virtual journey.

The scope of our library's design is to captivate the interest of the visitors by creating a convenient, accessible, and interactive environment. In the design, it is essential to take into consideration that users must have a large degree of autonomy and agency in the exhibition and use of the digital library. In that manner, we have developed a virtual librarian agent who greets the users when entering the building, offering assistance and the available options in a selectable menu; Figure 4 bottom shows the front-desk where the virtual agent welcomes the user, after the main entrance of the building.

Fig. 4. Top is the initial VR scene; bottom shows the front desk assistance.

Following the outcomes of our user study, we have implemented five case scenarios that demonstrate the use of a virtual library: that is (a) the *virtual tour* in the library, (b) *book lending*, (c) attending or organizing a *seminar/conference*, (d) booking and using a *virtual meeting room*, (e) booking a meeting with a *specialized mentor*.

Virtual library tour: In this first scenario, the user can take a tour of the virtual library to get familiar with the different spaces, while learning about the history of the library. The tour will answer many of the questions the user might have about the library (in general), it explains how the different processes work, such as indexing or borrowing a book, preparing literature reviews, or booking a room.

Book lending: In this scenario the users can browse and select electronic versions of books or proceedings they want to borrow/read. The general idea is to accurately simulate the procedure of book lending in VR; the users can read the contents or parts of the book in a quiet place inside the virtual library, or in assigned spaces (e.g., a virtual study room, see figure 5) allowing them to have social interactions that would have if they were visiting a physical library.

Attending or organizing a virtual seminar: Virtual conferences/seminars have recently become part of our daily lives. Following this trend, our library offers two options - to attend a pre-scheduled virtual seminar/conference, or to book a seminar room specifically designed to accommodate virtual attendants. The seminar room can be used for several occasions, such as university professors who want to present their works or lectures, students to present their homework, or companies to provide expert talks. Virtual seminars provide solutions to some of the limitations of the physical ones. Some of the solutions are that people from different locations can still

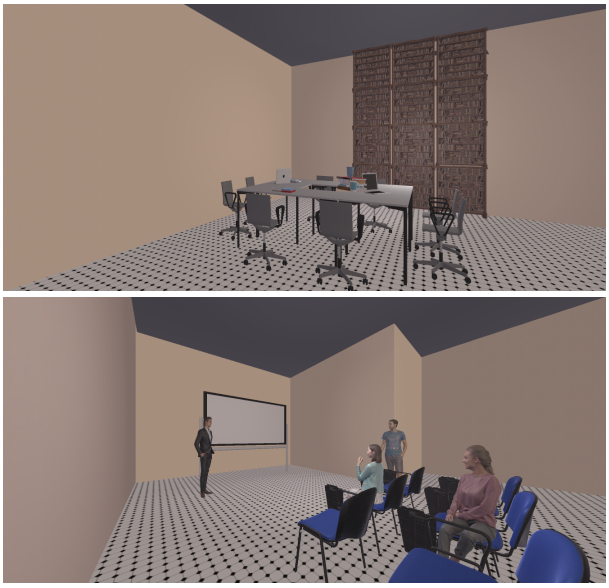

Fig. 5. The Virtual study room on top, and the seminar room on the bottom.

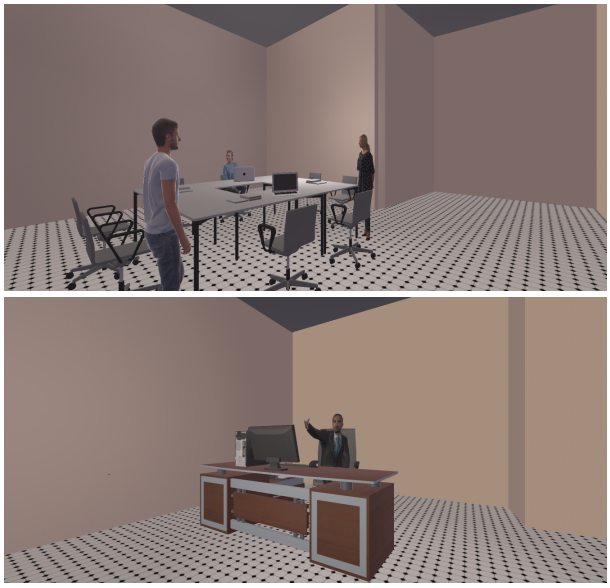

Fig. 6. Top image shows the virtual group meeting room, while the bottom one displays a meeting in operation with a mentor.

attend, a presenter who cannot book a big enough space for a crowd can now present in VR, there is no obstruction of view to the presenter, and the volume of the participants and presenter can now be managed to suit the viewers preference. As shown in Figure 5, a virtual seminar allows social interaction and networking between the participants, as well as the participants and the presenter, compared to the online meeting via a conference platform (e.g., zoom, MS Teams).

Booking and using a virtual meeting room: In the fourth scenario, we have implemented common virtual meeting rooms, where users can book upon availability. In these rooms, multiple users can join, upon invitation from the organizer, to perform a number of group activities. The rooms can be used for virtual group study sessions, brainstorming, group meetings, and socializing, in a similar way to the real world scenario. Figure 6 top illustrates a short meeting between three students that use the common room for their studies.

Mentor guidance: In this last scenario, we have implemented a virtual mentor booking platform, where the users can book slots with mentors (experts in their domain, e.g., librarian, scientists, academics) from a list of selected scholars that are collaborating with the library. The general idea is to assist the users with expert answers to any questions they may have regarding research or academic subjects. Figure 6 bottom shows a mentor discussing with a user in a virtual room.

VI. Discussion and Conclusions

In this paper, we have designed and developed a 3D virtual library, setting the foundation for the technological advances needed to be integrated in libraries in the general concept of a virtual environment/Metaverse. In that manner, we conducted a perceptual study to understand the current use of the library, and the limitations physical libraries present. We also identified the challenges and reasons why libraries have stopped being the meeting places for studying or scholar socializing, and why their visitors are decreasing with time. In addition, we portrayed the potential users of a virtual library, and understand their needs and expectations. We have reconstructed the Limassol Municipal University Library, in the aspect of a digital twin, using photogrammetry and 3D modelling. Our work revealed the apparent need of modernization of libraries in order to keep their importance in the new virtual era. Based on the outcomes of the conducted survey, we implemented five basic scenarios that users can meet in real world cases; take a virtual tour, borrow a book/proceedings via an online platform, attend or organize a seminar/conference, book a meeting room to participate in a group meeting (upon invitation), or meet with a specialized mentor.

Limitations: In contrast to the exterior design of the building, the interior has been modeled instead of being scanned. This leads to reduced accuracy in the interior design, and more specifically in modelling books or other small objects of the space. 3D reconstruction using photogrammetry requires increased resources to enable interior capturing and reconstruction, especially for numerous small objects, and an enormous amount of time to post-process and clean the data.

Even though there are many benefits in virtual libraries, there are also some limitations. Virtual Reality and Metaverse are relatively new concepts, and as shown in our study not everyone has access to a VR headset or has experience in using one (especially in social sciences). This in turn raises the question whether virtual libraries can still be a community hub for researchers and scholars, a place for their social interaction. The concept of a social virtual library is highly reliant in the number of its users. As the virtual library needs to encompass the social aspect of physical libraries, a low number of users would result in a library with minimal social interactions,

which is contrary to the concept of being a social hub.

Future Work: Future work will see the evaluation of our virtual library, studying various aspects of the implementations, such as its usability, user-friendliness, and educational impact. We would also like to make some suggestions for the smooth operation of virtual libraries in the future. As many libraries have stayed behind in terms of technology, both equipment and staff need to be upgraded to follow current trends in the digital era. In that manner, library staff needs to be trained on the technology; currently, a lot of libraries do not have a lot of VR or even IT experience, especially those that are located in remote places or are small in size with little available funds. Libraries, along with the academic institutions, should offer seminars about the use of emerging technologies and have headsets available at their premises so as to introduce to the community how immersive technologies could fit into such offerings.

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