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# Immersive Learning for Lost Architectural Heritage: Interweaving the Past and Present, Physical and Digital in the Monastery of Madre de Deus

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**Abstract:** This paper presents the creation of an immersive learning experience of the lost 16th-century Monastery of Madre de Deus, now the National Tile Museum in Lisbon, Portugal. It builds upon previous virtual reconstruction research which resulted in several digital models accompanied by paradata supporting the construction of different hypotheses. Reinforced by a review of relevant literature intersecting virtual heritage dissemination, research transparency and immersive learning, this paper details an immersive experience created with Shapespark 2.9.7, an online platform designed for architectural walkthroughs but repurposed for heritage dissemination. The result is a prototype that takes place in the existing building wherein the visitor can be transported to equivalent spaces of the 16th or 17th century to gain first-hand experiences of speculative pasts. While the constraints of the Shapespark platform necessitated a counterintuitive narrative workaround, this enabled creative associations to be made between the physical and virtual and the past and present. This paper identifies various advantages and disadvantages of the platform in the context of immersive learning and the long-term virtual sustainability of lost architectural heritage.

**Keywords:** immersive learning; immersive experience; digital storytelling; virtual reconstruction; paradata; intangible heritage; lost architectural heritage; Poor Clares; Colettine monastery; Historic Building Information Modelling (HBIM)



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## 1. Introduction

Lost architectural heritage refers to buildings, structures, or other physical features of the built environment that have been damaged or altered over time to such an extent that they are irretrievable through physical experience alone. This loss can occur for many reasons like neglect, disaster, demolition, or renovation works. Such heritage is commonly known to us through sparse sources of multiple and varied layers of the past that are often uncertain and contradictory. Each lost artifact uncovers cultural, social, and spiritual significances embedded within dynamic relations that are ambiguous from a contemporary mindset. When revealing lost heritage, both tangible and intangible, it is our responsibility in the present to weave together a narrative that respects the form of life, beliefs, difficulties, and accomplishments of those who came before us as well as those who we intend to receive it, both in the present and the future. This narrative requires a nuanced approach, acknowledging the complexity of historic sources, physical evidence, and their deciphering. It demands the accountability of the narrator, who must encourage a connection between the past and present that contributes lessons about human experience.

### *1.1. Research Objectives and Knowledge Gaps*

This paper builds on earlier research conducted during a fifth-year Integrated Master's course in Architecture at Instituto Superior Técnico, Lisbon, in 2021 [1]. In this course, virtual reconstruction hypotheses were created for several spaces believed to be associated with the monastery's original 16th-century core. This was a building block to the current research, which deciphers and narrates this knowledge in an immersive learning environment. Previously, the research results were presented in 2D portfolios, incorporating text and visuals that explained the sources and decision-making processes of each hypothesis, a process commonly referred to as paradata. While crucial for the transparency of this research, this form of dissemination overlooked the potential to leverage the 3D modelling content to create immersive experiences of the past.

Within this context, the present research can be summarized by the following three objectives. Firstly, there is the objective to publicly communicate the results of ongoing research into the lost 16th-century Monastery of Madre de Deus as a prototype to take this research into future phases. Secondly, this paper addresses current knowledge gaps in the realm of virtual heritage. It evaluates a cost-effective, time-efficient path to overcome the lack of existing platforms suitable for the creation of immersive learning environments for heritage. Thirdly, this paper contributes a narrative strategy for tailoring immersive learning environments to lost architectural heritage where sparse traces of the past remain intact. Altogether, this research establishes a relevant direction for similar case studies of lost architectural heritage supported by a literature review of recent studies intersecting virtual heritage dissemination, authenticity, and immersive learning.

Despite the increasing digitization and hyperconnectivity of our world, there are few options available to showcase digital heritage online as important cultural artifacts and sustainable scholarly resources [2]. While there are several existing platforms for the dissemination of digital models online, they are limited in their capacity to suit the needs of heritage for immersive learning environments specifically. A recent wide-ranging survey of existing institutional and commercial repositories notes common limitations such as the inability to host metadata of how models are created, the inability to experience temporal differences or changes to an object, and the inability to create online links to archival records or to create customizable learning experiences [3].

In response to these issues, scholarly interest in open-source video game engines like Unity and Unreal has increased over the past decade [4–7]. These tools, unlike digital repositories, can provide free options to create immersive experiences but come with subscription costs when one wishes to publish content online. Despite the positive implications and growing interest in video game technologies for virtual heritage, there is still a large knowledge gap between heritage documentation and video game development which typically requires advanced programming knowledge [8–10]. One reason for this is likely the lack of a strong academic community to share learning resources and updates about these ever-evolving tools [11] (pp. 104–105). The learning environments in game design also work best through an in-depth use of reward systems and user feedback [12] (pp. 87–89), requiring a lengthier narrative design process and further advanced programming skills that were beyond the scope and time constraints of the present phase of research.

Above all, this research addresses these abovementioned knowledge gaps presently faced by the virtual heritage community, while questioning how virtual experiences can contribute to the experience of lost architectural heritage through immersive learning. This required choosing a user-friendly platform that could meet the specific learning objectives of the project while factoring in the existing content produced from the past phase of research. An important learning objective was to better understand how physical traces in the building today are key aspects in understanding the 16th century. The virtual learning experience needed to be able to integrate these elements in a way that would allow potential physical and virtual visitors to understand their relation to the past. The Shapespark platform [13] was selected for its seamless integration into the Historic Building Information Modelling (HBIM) environment used in previous research. It does not need

advanced programming skills and offers preset features like hotspots and information embedding that are essential for providing in-depth explanations, 3D models, images, and even links to other online archives. While Shapespark is typically utilized for generating virtual walkthroughs of architectural designs, this paper shows how it can be adopted for the purposes of heritage dissemination including some of the obstacles and advantages which have been encountered.

### *1.2. From the Monastery of Madre de Deus to the National Tile Museum*

Queen Leonor built the Monastery of Madre de Deus upon a pre-existing palace along the Tagus River in Lisbon, Portugal, in 1509. At this time, the monastery not only served as an exclusive retreat for nuns of the Colettine Order but also functioned as a repository for relics which drew in numerous pilgrimages and crowds for religious festivities [14]. The second oldest among the reformed Clarissa monasteries in Portugal, it was inhabited by the original seven nuns from the Convent of Jesus in Setúbal in 1491.

The Poor Clares, or Second Order of Saint Francis, were founded by Saint Clare of Assisi in 1212. In the 15th century, Saint Colette of Corbie (1381–1447) restored among the Poor Clares an ascetic life echoing the Franciscan commitment to emulate the life of Christ, marked by the renunciation of possessions and worldly pleasures in favor of a poor life. These nuns lived in a state of strict enclosure, meaning they could not leave the walls of the monastery. They lived a life of strict discipline involving penance and ascetic rigor. They dressed in humble habits, walked barefoot, fasted, continually abstained from the pleasures of life, and engaged in structured religious training.

The monastery was located outside the city of Lisbon in the zone of Xabregas where Queen Leonor lived and wrote extensively. During her life, Queen Leonor channeled religious and spiritual investments into the zone of Xabregas, with the monastery of Madre de Deus receiving the most important collections of sacred art, precious relics, and other objects. This Colettine House established by D. Leonor promptly gained favor among the women of the Portuguese high nobility, serving as both a cherished religious sanctuary and a favored setting for the royal family's devotional gatherings.

Imagining how the monastery looked at this time is challenging due to the absence of comprehensive historical accounts and since there are no other examples which contain the blend of Mudéjar and Manueline styles which resulted from the monastery's construction upon a former palace. Instead, what remains are elusive fragments of diverse historic sources. Furthermore, the monastery at this time would have existed only for a brief period since, after Leonor's death in 1525, King D. João III initiated extensive renovations around 1555. The expansion was undertaken in response to complaints about the monastery's size and persistent flooding, which led to the consecration of a new church in 1624, elevated several meters above the previous structure. The addition of a new cloister, refectory, infirmary, bell tower, and a private royal balcony within the new church transformed the layout that remains visible today. These changes completely reconfigured the spaces from the 16th century.

In the 19th century, the monastery underwent a conversion into the D. Maria Pia Asylum. This occurred because of the dissolution of the religious orders in Portugal in 1834, which led to wide-scale secularization and redistribution of monastic properties and assets by the state. The architect José Maria Nepomuceno began this transformation in 1871, but it was not completed until 1899 by Liberto Telles, the public works director of the time. Through this conversion, the architect's proposal reclaimed the characteristics of the lost Manueline architectural elements that had largely disappeared from the 16th century because of King D. João III's expansion. Consequently, the current spaces largely exhibit a 19th-century Neo-Manueline conversion effort which aimed to capture the spirit of the original monastery. The final major spatial conversion occurred in 1965, which resulted in the establishment of the National Tile Museum (Museu Nacional do Azulejo) in 1965.

The National Tile Museum today holds great cultural significance (Figure 1). It actively preserves the Portuguese tile-painting tradition while engaging the public in diverse

educational campaigns to valorize the tradition. It holds a permanent collection of tiles from various historical periods within the spaces of the former monastery. Nevertheless, many visitors remain largely unaware of the history of the building as an important religious sanctuary during the Portuguese Renaissance, and even less is understood about the enclosed life of the nuns who lived there. This research is thus situated within the necessity to make visitors better aware of the past without taking away from the significance of the museum's current activities and collections.

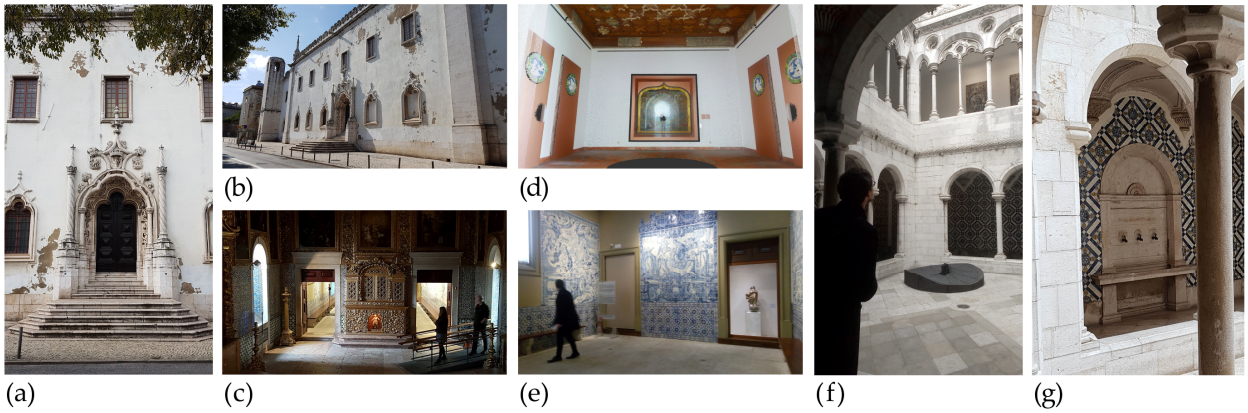



**Figure 1.** A series of photographs of the existing space showing (**a**) the main portal of the church, (**b**) the south-facing façade, (**c**) the Low Choir, (**d**) the Chapel of Queen Leonor, known historically as the Arab Room, (**e**) the D. Manuel Room, (**f**) the Small Cloister, and (**g**) the fountain of St. Auta.

As one of the most visited museums in the country, especially at a time of mass touristification in the city of Lisbon, the decision to create an online immersive experience was chosen until a better means of integrating it into the physical space could be proposed that would not contribute to overcrowding the narrow exhibition spaces of an already highly populated visitor space. Furthermore, numerous spaces important to the daily life of the nuns have yet to be reconstructed in this phase of the research. Spaces such as the dormitories, kitchen, and refectory are essential to a comprehensive vision of the nun's form of life, yet these spaces currently house tile collections which a physical intervention would compete with. Thus, since a comprehensive virtual reconstruction has not yet been concluded, it was deemed best to exhibit the ongoing work in an exclusively virtual environment. While the project aspires to eventually reconstruct all the monastery's various historical phases, the immersive learning experience presented in this article focuses only on the birth of the 16th-century monastery, a period least understood by experts today.

## 2. Literature Review

### *2.1. Virtual Heritage Dissemination*

The use of digital platforms by cultural institutions like museums and other learning institutions has grown in recent years, creating numerous ways of disseminating knowledge about heritage assets online, either in databases, archives, virtual tours, or other immersive learning experiences made possible by augmented reality (AR) and virtual reality (VR) technologies. Such practices have intensified following the COVID-19 pandemic, which forced many cultural institutions to redefine and reimagine forms of public engagement and storytelling, with many virtual formats replacing physical visits [15–17]. Google Arts & Culture is a well-known example which provides online access to numerous virtual experiences made through partnerships with significant museums and other public institutions globally [18]. Already, the results of studies suggest these trends are no temporary phenomenon or crisis response. Virtual travel is likely to continue in a post-pandemic world due to a growing sense of eco-anxiety and concerns over the sustainability of physical travel [19,20].

Although the term evokes many possible definitions, immersive experiences typically refer to virtual experiences made navigable online through a smart device, computer screen, or VR headsets which replicate a guided visit to a physical place. Often, immersive experiences can take the form of a virtual tour providing a sequentially designed walkthrough within which the virtual visitor is pointed to culturally significant objects, architectural details, or other aspects, akin to the experience of an in-person visit. Descriptions of these may be enhanced through the convergence of other media, beyond what is possible in a physical visit, for example, with the inclusion of videos, explanatory digital models, images, text, or other content. This enables visitors to view and interact with a simulated environment that facilitates learning about both tangible (physical artifacts) and intangible (cultural and historical context, documented practices of life) aspects of a place [21–23].

The inclusion of intangible history in virtual heritage is particularly relevant in consideration of a more inclusive and sustainable understanding of heritage today [24]. Since the 1970s, international documents defining the criteria of heritage protection began incorporating not only the tangible protection of objects but increasingly intangible aspects of heritage [25]. Examples of intangible heritage in the context of architecture could include building techniques, uses of spaces, ritual practices, ceremonies, events, oral histories, or other invisible cultural meanings associated with an object or place. The significance of this trend has increased within the last two decades, contributing to what has been referred to as a new paradigm which recognizes the importance of transmitting memory and traditions to future generations [26]. Within this context, digital modelling processes, like HBIM, have been touted for their contribution to the sustainability of intangible cultural memory as employed not only in the documentation and management of heritage but also as a means of visualization and cultural learning [27–30]. This process often leverages the dissemination of virtual heritage to draw attention to physical sites.

Several case studies highlight the diversity of approaches that researchers have taken to relate physical and virtual places. The case of the Canadian Parliament buildings is one example where physical visits have been substituted by virtual ones during a lengthy rehabilitation campaign which will close doors to the public for at least two decades [31,32]. In this case, the virtual experience temporarily takes over the physical experience to continue the dissemination of the popular destination. A virtual tour of the Castle in Corsano, Italy, uses virtual reality to permit access to a physically inaccessible place, allowing first-hand experience of the tangible and intangible history of the place [33]. Here, the virtual experience contributes to the site's valorization in hopes of an eventual reopening of the site. In Romania, a series of wooden churches were incorporated into a virtual learning experience to connect visitors to fragile heritage sites to promote their cultural significance and protection [34]. This approach seeks to leverage digital surveying data for public engagement and conservation assessment. Virtual experiences have also proven effective for remote learning within higher education contexts to enhance architecture students' understandings of heritage, as is the case of the Pantheon in Rome [35]. In this course, the virtual experience enhances textbook learning by allowing students to explore a site first-hand while eliminating the need for costly international travel. Far from being an exhaustive list, these are some examples which use digital content to permit the continual access and sustainability of architectural heritage and its intangible values and practices.

Despite the increasing adoption of virtual experiences for such purposes, there are many questions as to how these experiences impact our relationship to physical places and their histories. Namely, what kind of relationship should a virtual experience have to the physical place which it represents? Is the digital meant to replace the physical or can the two experiences be mutually beneficial for learning about the past? How do we define authenticity in such cases, and is it even possible to do so in an age of mass simulation [36]? These questions are especially pertinent in cases which seek to replicate experiences of an existing, already publicly accessible place.

### *2.2. Authenticity in Virtual Reconstruction Research*

The visualization of lost architectural heritage through virtual reconstruction research instigates a complex relationship between the physical and virtual that raises questions of authenticity. Virtual reconstruction typically uses digital modelling from diverse datasets to visualize places which no longer exist or have been modified so greatly over time as to make physical visits alone ineffectual to achieve a tangible understanding. According to the Principles of Seville, virtual reconstruction may occur at a single point or multiple points in history and is to be grounded in studies conducted by experts in fields such as architecture, archaeology, and history. It should be substantiated by physical evidence, historical texts, and comparisons with similar places or objects [37] (p. 3).

Such models are often important forms of public engagement about heritage, yet, some have criticized that virtual environments can create an even greater distance between the present and past. Despite all efforts to recreate authentic virtual environments with high visual and auditory fidelity, there are still many limitations that give us a sense of "immateriality and sterilization" as a result of the absence of patina and traces of life, as well as the haptic limitations that such environments have been unable to overcome in existing technologies [38] (p. 51). In contrast, the notion that high visual fidelity is important for authenticity has also encountered increasing scrutiny in recent years. Despite the advancements in contemporary 3D reality capture technologies, which can produce increasingly refined and geometrically precise representations, such attributes do not inherently ensure authenticity. The temptation to conflate authenticity with accuracy might be better avoided altogether, each having their own distinct roles [39,40].

Additionally, some criticism has emerged about international guidelines such as the London Charter and Seville Principles for having exhibited an excessive preoccupation with recreating the original as the primary determinant of cultural authenticity [40]. Instead, researchers have suggested that any definition of authenticity is itself based on evolving, often highly subjective criteria depending on different individual or collective opinions, cultural contexts, societal changes, and differing value systems that are impossible to define in a universal way [40–42]. Authenticity for many researchers, therefore, is not only about faithful representations of the past but also a much more dynamic process including (1) how these pasts are constructed, (2) the development of a virtual heritage project itself, and (3) the living experiences of those who are intended to find meaning in it [41]. This understanding of authenticity shares UNESCO's reformulation of criteria for listing objects and sites as world heritage that was advanced in the Nara Conference of 1994 [43]. Here, value judgements and criteria of authenticity differ greatly across cultural perspectives, which makes it impossible to base authenticity on fixed criteria. Instead, a commitment to authenticity implies the necessity to evaluate and assess heritage properties within their respective, often complex or contradictory, cultural contexts.

For over a decade, the Principles of Seville has stood as the most authoritative guideline for definitions of authenticity in virtual heritage. They were formulated firstly in 2011 to extend the earlier London Charter's principles into the field of virtual archaeology. Overall, the principles equate authenticity to the scientific validation of hypotheses and degrees of accuracy based on available information. One criticism of the principles from what has been discussed above is that they implicitly bias a search for the original as the main goal of virtualization, with scientific categories that in reality cannot be fully upheld [40]. One of the most direct claims of the principles is: "Since archaeology is complex and not an exact and irrefutable science, it must be openly committed to making alternative virtual interpretations provided they afford the same scientific validity. When that equality does not exist, only the main hypothesis will be endorsed" [37] (p. 6). Here, the judgment of equality rests on many factors like the interpreter's opinions, biases, and cultural background, as well as an understanding of the context in which the historic records used to create a hypothesis were produced. Morcillo et al. have suggested, therefore, that the definition of scientific validity be defined to incorporate "truthful and credible values for different versions of an object, different uses through time, different cultural contexts

and memories, and maybe even future projections of meanings" [40] (p. 41). In this way, research transparency in virtual reconstruction would be paramount to disclosing claims or definitions of authenticity.

Another important international declaration on virtual heritage is the 2006 London Charter, which was born out of the research community of the late 1990s and early 2000s. Its authors saw a growing necessity to define guiding principles to justify the scientific nature and progress of the newly emerging field [44]. At that time, a sustainable solution to transparency in virtual heritage was particularly important due to the novelty that virtual tools introduced into the study of history. Thus, while authenticity is not a term employed or directly addressed by The London Charter, researchers who contributed to its formulation have since reflected on what it implies about authenticity [45]. For them, authenticity is referred to as the ability to scientifically evaluate and assess a visualization outcome [45]. This includes a formal representation of the reasoning process for generating a visualization outcome, along with the primary data used and its transformation process. In this context, transparency is meant to ensure the intellectual accountability of the research processes that led to produce the digital artifact, not guarantee the authenticity of the result [45]. Through an adequate means of communicating transparency, others can determine for themselves the validity of the work in question. That being said, researchers must be cognisant of the range of interpretations that potential visitors are able or willing to give to virtual heritage experiences.

An important aspect to consider within this scope is the concept of paradata. According to the London Charter, paradata refers to how a researcher understands and interprets the available data involved in a given virtual reconstruction project [44] (p. 13). Paradata should be included in any database of a virtual model of this kind to clarify the results of the work. Considering that there are numerous different interpretations of an artifact or historical data possible, paradata ensure the transparency of the research. They involve describing the steps taken in the interpretation and the reasoning process of reconstruction regardless of how they define such criteria. In this way, the documentation of paradata aims to provide other interested parties with a robust understanding of the various objectives and environments involved, as well as the dependability of certain visualization techniques used to achieve the results [46]. They are crucial for the transparency of the research narrative, showcasing how arguments were formed and offering insight into the visualization journey with all its inherent uncertainties and biases made visible [47].

### *2.3. Immersive Learning*

Although it is always ideal to learn about architectural history in its genuine physical environment, a spatial understanding of the 16th-century Madre de Deus could only be achieved virtually due to the extensive spatial transformations that have obscured its history. By providing first-person immersive experiences, the use of VR can provide some semblance of access to a vanished past. Such immersive experiences can also become learning tools to transmit additional knowledge in the form of text or other media mapped onto three-dimensional experiences of a virtual world. In these ways, how might an immersive learning experience provide visitors with access to spaces lost to time, while transforming their interpretation of the existing place in ways that a physical visit cannot?

At present, there are numerous VR applications which generally appear in two popular forms: Desktop-VR and Headset-VR [48] (p. 962–965). Desktop-VR utilizes a standard computer monitor, mouse, and keyboard for visual display and interaction. It is the most cost-effective and simple option due to the widespread availability of personal computers and the minimal training involved for users to immediately engage in this content. As an alternative, Headset-VR employs a head-mounted display for specialized viewing. It provides a greater sense of immersion and, as many studies have shown, achieves better memory performance [49] (p. 1218). Despite this, research has struggled to comprehensively understand how effective these environments are for learning since there are still a lot of unknowns, different disciplinary knowledge at play, and because the research often yields

contradictory results [49] (pp. 1213–124). Regardless, many educators and researchers have posited numerous advantages of this kind of learning for closing the gap between theory and practice in diverse examples of science and technology training, though less focus has been given to learning in the humanities [50] and heritage [51] in general.

Within the experience of architectural heritage, however, one could speculate on various benefits across existing research. Some suggest that learning can take place simply through the emulation of a genuine context, as long as it is able to induce a sense of presence [52]. Furthermore, while reading increases cognitive efforts due to the necessary filtering and interpretation of symbols in text, immersive experiences can reduce the strain of interpretation by presenting information directly [53]. This is clearly an advantage to learning about architecture. This is supported by existing research in psychology that indicates active interaction in virtual spaces yields higher mnemonic benefits than passively watching instructional videos, indicating a positive correlation between the spatial interactions in VR and learning outcomes [54,55]. Furthermore, immersive experiences can help trigger episodic memory, which in turn enhances the retention of meaningful, personalized learning experiences [56]. Episodic memory is a type of long-term memory that involves the conscious recollection of past experiences, including spatial context, time, place, and associated emotions, among other factors that allow us to re-experience events of the past [57]. It has important implications for learning because it can help individuals remember the context in which certain information was acquired, allowing personal connections to form between different experience and subject matter [57]. What is important for learning in immersive virtual experiences is that they leverage our innate episodic memory by providing interactions to create lasting, transformative knowledge [56]. Researchers suggest that an effective immersive learning experience should therefore aim to elevate a user's levels of perception and cognition through the creation of interactive spatiotemporal connections of objects and spaces [58–60].

Aside from the learning benefits, there are other aspects related to the connection between the virtual and physical that should be mentioned. VR has been increasingly relevant for addressing accessibility to heritage [61] while re-situating learning in experiential contexts to create a sense of presence [62] in places that are otherwise impossible, difficult, too costly, or unethical to visit [63]. Virtual experiences might similarly aid in enhancing a visitors' eventual physical experience of a place, providing insights and context. Studies in the tourism industry provide some reassurance to this hypothesis. Usually, users of virtual experiences respond that they offer helpful complements and background information to eventual physical experiences of a site, rather than understanding them as replacements of such visits [64,65]. Others suggest that positive interactions in virtual experiences may encourage visitors to visit a physical site [66]. Thus, virtual experiences have the capacity to positively transform our encounters with physical places, introducing new forms of knowledge that the limitations of physical visits cannot.

## 3. Materials and Methods

### *3.1. Materials from Previous Virtual Reconstruction Modelling with HBIM*

The immersive learning prototype was created first by analyzing prior research results conducted by students of an HBIM course undertaken within the context of a fifth year of the Integrated Master of Architecture program at Superior Técnico, Lisbon, in 2021. In this course, students were involved in virtual reconstruction hypotheses with the aim of accurately representing each space associated with the monastery's original 16th-century core. The projects utilized a combination of sources such as point cloud data, an archaeological survey, paintings, and graphic and historical descriptions, among other sources found throughout the term [1] (p. 6219–6222). Through the interpretation of these sources, as well as some previously outlined hypotheses, students worked with their professors and invited historians to arrive at various virtual reconstruction hypotheses of the building.

During the semester, the 21 students arranged themselves into eight projects, each of which focused on a particular space or time frame within the monastery. These spaces

all relate to the founding church nucleus. This includes the Small Cloister, the Chapel of Queen Leonor (known historically as the Arab Room), the Reserves Room, D. Manuel Room, the Low Choir, and the Bell Tower (Figure 2). Several modelling tasks also included parts from the 17th century and 19th century. Additionally, the building as we see it today was also modelled to better understand the building's spatial evolution.

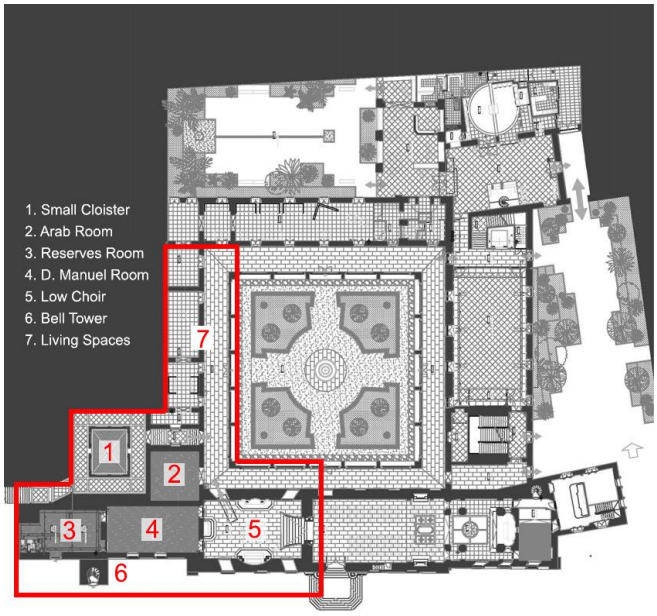



**Figure 2.** Plan of the ground floor of the National Tile Museum today indicating spaces believed to originally belong to the 16th-century Madre de Deus outlined in red.

While this space-specific approach might be criticized for lacking a holistic comprehension of the building, the students were always aware of the proposals being made by their classmates in weekly group presentations throughout the term. The pedagogical approach was planned in a manner to allow monitoring of the development of research hypotheses closely and continuously throughout the semester in weekly presentations. This interaction was documented in visual–textual portfolios which accompanied the final models. The portfolio documents were designed to collect and present what has been defined above in Section 2.2 as paradata. A crucial component to the immersive experience was the analysis of these portfolio documents which recorded the methods, sources, and critical thinking processes of their work. Students not only visualized hypotheses but also justified their work with historical sources to articulate their decision-making processes. The resulting portfolios contained all the references necessary to build a virtual experience that could re-communicate the research, sources, and thinking that provoked the virtual hypotheses.

All of the models of this past phase of research were created through the process of Historic Building Information Modelling (HBIM), a methodology first proposed by Murphy in 2009 as a strategy to adopt the process of Building Information Modelling (BIM) to historic buildings [67]. Typically, the process uses digital documentation strategies such as laser scanning and photogrammetry which result in a millimeter-precise dataset from which to build accurate geometries. However, since BIM was intended for modern construction, which relies heavily on standardized components, the irregularities and complex geometries found in heritage have presented numerous challenges to creating these models [68–71]. For this, Autodesk Revit 2021 was the software of choice in this project, being one of the most popular existing programs with an existing body of literature on overcoming these challenges.

To date, the process of HBIM has found relevance for numerous applications in the field of heritage, ranging from cultural recovery and dissemination purposes [72,73] to management, conservation, and rehabilitation purposes [74,75] or a combination of both [76,77]. In some

instances, like those of this case study, these models may also include historical drawing sets or other relevant historical information to make informed speculations about a building's past phases. The use of HBIM also has important implications for the long-term sustainability of virtual heritage, as specified in the London Charter and Principles of Seville discussed above. These declarations seek to promote not only the intellectual but technical integrity of virtual heritage. Important to this integrity is the fact that HBIM tools use a data model known as the Industry Foundation Classes (IFC), which means that geometry and metadata are accessible through an interoperable, open-source and platform-neutral tool [78]. Therefore, even in the face of obsolescence, the tool has measures to ensure its data are recognized and accessible.

The methodologies and results of the HBIM modelling process used in this research have already been discussed in a previous publication [1]. In that publication, images of the research sources and how their interpretations were used to create different hypotheses in an HBIM environment have already been discussed at length. Rather than repeat this work, it is worth summarizing the reconstruction hypotheses briefly below to introduce the spaces of the monastery and to better explain how the narrative approaches taken in the learning experience would need to incorporate the diversity of sources and results:

1. An "As-Found" Model of the National Tile Museum: This group focused on digitally modelling parts of the National Tile Museum building as they exist. The modelling was conducted primarily through point cloud data collected at a prior date by the professors of the course [1] (pp. 6220–6221). The objective of this group's work was to accurately model spaces related to what are believed to be the original spaces belonging to the Monastery of Madre de Deus. The model was meant as a comparison against the 16th-century reconstruction. As much as possible, the model replicates the existing conditions to give reference to the physical space, though it was challenging to replicate all the ornate details of the gilded woodcarving and the painted scenes one the tiles that contribute to the building's character.
2. The 16th-century Church—Hypothesis 1: This group delved into the 16th-century church of Madre de Deus by challenging hypotheses established previously by the historians Pais and Curvelo [79]. The historians proposed that the original church's location be in the present D. Manuel Room due to a literal analysis of the painting "Arrival of the Relics of Saint Auta," [80] deriving from the 16th century, which shows the river by the church's south façade. Instead, students contested this arrangement, acknowledging the possibility that the role of the painting was more figurative than literal. This resulted in a shift in orientation of the main façade from the west to the south. They also compared the dimensions of existing point cloud data to measurements found in historic text which outlined the dimensions of the original church. In addition, they speculate that the original portal may have been relocated from a different location as indicated by an unexplained excavation indicated in 19th-century drawings [81]. As a result, the students located the 16th-century church where the Low Choir is located today, rather than the D. Manuel Room as speculated by the historians. This revised proposal would imply a similar layout to what is seen in the Convent of Jesus today, with the choir located west of the main nave.
3. The 16th-century Church—Hypothesis 2: This theme tested a previously developed written hypothesis of Madre de Deus's 16th-century church by João Simões which drew theoretical connections to other architectural examples of the Colettine reform [82]. Simões speculated that the building adhered to architectural precedents found in the Convent of Jesus in Setúbal and the Convent of Saint Clare in Gandía. The students incorporated this perspective, while making slight adjustments to the proportions of the walls based on point cloud data and based on a comparison of historic cartographies. As a result of this proposal, the church would take the place of both the D. Manuel Room and the Low Choir.
4. The 16th-century Church—Hypothesis 3: This hypothesis reconstructed the 16th-century Madre de Deus using three reference paintings. Historians entertain the notion that

three church paintings initially housed by the church might indeed portray it. This hypothesis explores aligning the façade—"Arrival of the Relics of Saint Auta" [80]—and two interiors—"Saint Francis Delivering the Statutes" [83] and "Tryptic of the Presentation of the Child" [84]. The model adheres to dimensions outlined in a written contract providing measurements from 1517 [85] (p. 76) and measurements from point cloud data.

5. Arab Room: The space formerly known as the Arab Room is situated in what is today known as the Chapel of Queen Leonor. This space was known to be part of the original palace space owned by Álvaro da Cunha's widow and is famous for its wooden Mudéjar ceiling. The rope motif of this ceiling prompted Queen Leonor to establish the monastery upon this existing palace. The theme reconstructed the chapel's original ambiance, including tile work, floor patterns, and modelling an altar from historic drawings which depict it housed in this space.
6. Modelling Nepomuceno's 19th-century Plans: Following the dissolution of religious orders in 1834, architect José Maria Nepomuceno surveyed the Madre de Deus Monastery for its conversion into a Casa Pia asylum. His plan categorized areas into red (signifying what was to be built), gray (signifying what was found and maintained), and yellow (what was found and planned to be demolished) [81]. These layers' interpretations provided insights into the building's evolution, crucial for understanding its chronology. The task involved modelling two interpretations of Nepomuceno's intervention: what was supposedly built and what was encountered initially. Additionally, these models incorporated present point cloud data to ascertain the surviving remnants of Nepomuceno's modifications. Due to the analytical approach of this research, it was not deemed essential to experience these two models separately but rather to visualize them as models within the immersive experience.
7. Low Choir: The space that is today still known as the Low Choir likely served as the entrance to the pre-existing Mudéjar palace by the Tagus River before becoming a monastery. Its function as a choir after King D. João III's expansion is clear, but its original role in the 16th century remains uncertain—whether as the original church or choir. This model explores the hypothesis that the space maintains its function as the original Low Choir. Referring to a 1639 testimony written by the nuns of the monastery that mentions a previous corded ceiling [86], this group speculated on vaulted ceilings of the space as the main character-defining element, in reference to the Convent of Jesus in Setubal. Other additions include a proposal for an altar membrane, the insertion of a Persian carpet supposedly belonging to the space, and the relocation of choir stalls existing today in the floor above their initial location.
8. The 17th-Century Church: Between 1551 and 1624, King D. João III expanded the existing monastery due to nuns' complaints of recurring floods and the desire for larger living spaces. To grasp the building's evolution, this project reconstructed a schematic overview of Madre de Deus in the 17th century by digitally interpreting Nepomuceno's façade drawing to reveal the façade's pre-asylum state and using point cloud data of the existing church interior, which has remained largely unchanged to this day. The model includes the Main Cloister which is believed to be the same as what is seen in the building today, suggesting it could be a useful space to link past and present.

Following the analysis, the creation of an immersive learning experience of the Monastery of Madre de Deus was undertaken with the objective of communicating a deeper understanding of the building to the public. Taking this past research as a building block, the challenge of this phase was to design a narrative sequence that could tie these models of the past into a coherent learning experience both spatially and temporally. This task was complexified by the fact there were many reconstruction hypotheses overlapping in the same space, each using the same historic sources as supporting evidence but in different ways. The differing church hypotheses are a clear example of this. Not only do the three proposals of the 16th century exist simultaneously in the same space, they also sometimes physically extend beyond the confines of a single room, conflicting with

the spatial hypotheses of other adjacent hypotheses like the Low Choir and Arab Room. Adding to this complexity, the immersive experience would need to educate the public in such a way that they might develop a better understanding of the physical traces which still exist in the present today. To meet these objectives, it would not be enough to simply visualize the results of this past research. Instead, it was necessary to reconcile a number of conflicting aspects that emerged out of past works.

### *3.2. Designing an Immersive Learning Experience in Shapespark*

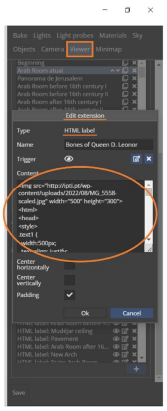
After all the projects were completed, it was necessary to find a tool capable of providing public access to the model space. While 360 images and videos are a common form of engagement in virtual tours, these would have little relevance for the Madre de Deus case study since this technology is limited to capturing what is visible in the present. Indeed, the museum already has a virtual tour of the present [87]. Instead, what was needed was a method of immersion into the virtual reconstruction models previously produced. For many cultural institutions, a lack of funding and interdisciplinary skills prevents public accessibility to digital heritage [88,89]. Depending on the processes chosen, making digital heritage accessible is time-consuming and demands the continued availability of different experts like historians, architects, and programmers. This can create public barriers to culturally significant content since digital models are normally produced by and for select experts with the extensive educational backgrounds often necessary to navigate the software used to create them [90].

Shapespark was chosen in consideration of the short time span of the project. It is a tool normally used for architectural marketing, visualization, virtual walkthroughs, and similar applications in the design and construction industry, meaning that it was designed for people with experience in common modelling programs used in architectural heritage. The tool proved advantageous because of the small learning curve required. A great advantage of Shapespark is that it is not necessary to have extensive knowledge of advanced coding languages to be able to use it. Furthermore, it can be experienced equally in both Desktop-VR (including smartphones or tablet) and Headset-VR. Therefore, those who have the availability of a headset can take full advantage of it without any additional setup needed. The availability of customizable interactive hotspots was another advantage and highly important factor to consider when creating learning experiences of virtual heritage. In addition, it also has a relatively low subscription cost considering there is no file size limitation when compared with other options reviewed [3] that have much smaller file size limitations that would be nowhere near sufficient for the purposes of this case study. Despite its ease of use, there are no other known projects that currently use it as a tool to disseminate virtual reconstruction research.

The creation of an experience in Shapespark begins by importing a digital model directly from modelling software like Revit, SketchUp, 3ds Max, and Blender or from a number of file type formats common to other programs. All textures and objects must be placed within the digital modelling environment, though it is possible to add illumination either through points of light or sun simulation later within the platform itself. Users can also adjust the opacity, reflectivity, or appearance of materials within the platform. Users can then customize the navigation of the scene with pre-defined camera positions to guide visitors and add hotspot annotations, adjustable in appearance according to pre-defined icons, through which additional media like text, images, and videos can be inserted.

Although in-depth coding knowledge was not required, some HTML knowledge was necessary to control the visual output of the integrated media in the hotspots. Figure 3 illustrates how this language was integrated. Once initially resolved, a consistent coding base was used for each. From this structure, it was possible to associate information to each icon with greater efficiency and consistency. In the case of image and video media, these needed to be previously hosted online and be accessible through a hyperlink. The platform has no storage capacity for additional files. When everything is set, the virtual world can be published online and accessed through a weblink or embedded onto an existing

website. The scenes are then viewable through a web browser where visitors can navigate throughout the virtual environment in real time. Here, visitors can explore freely or be guided by pre-defined camera positions through a menu. The result can be viewed on any device with an Internet connection.



```
<img src="http://ipti.pt/wp-content/uploads/2022/08/MG_5558-scaled.jpg"
width="500" height="300">
```

Code to insert an image

```
<html>
<head>
<style>
.text1 {
  width:500px;
  text-align: justify;
}
</style>
</head>
<body>
<div class="text1">
<h1 style="font-size:180%;">The Bones of Queen D. Leonor</h1>
```

Code to insert a title

```
<p>It is in the entrance of this space that we can find the tomb of Queen D. Leonor.
In <i> Noticia da fundação do Convento da Madre de Deos das Religiozas
Descalças de Lisboa, </i> (1639) written as a fictionalized dialogue between nuns
of the former monastery, we can discover many clues about the original state of
the building that will be included throughout the virtual visit. <br> <br>

From the fictional nun Vigaria, we can understand the reasons for re-locating the
bones of Queen D. Leonor here: <br><br>

<i>"Vigaria: An attempt was always made to preserve this humility so that she
would remain a rare example, because if not for this, King Dom João, the third
one, when you came to the Great Cloister (and they took her out of the picnic
where she was) could make her a sumptuous sepulcher, but they did not want to,
before when all the royal people came, who then had their translation, and told
them that the bones would be eaten if they were loose on the ground, they put
them in a clay vessel, after the Infantas Dona Izabel and Dona Maria had cleaned
them in towels, and I understood that, except for DelRey's intention to keep this
humility, that the void would not be as humble as the grave." </i> (Translation from
16th century Portuguese by Maria Nazário). <p> <br>
```

Code to insert a text box

```
<a target="_blank" href="https://purl.pt/31162/1/html/index.html#/1">The original
Portuguese text in its entirety can be accessed here</a> <br>
```

Code to permit access to external sites

```
</div>
</body>
</html>
```

**Figure 3.** Example of HTML coding used in Shapespark.

Despite not being the objective of the program, its structure and range of controls proved useful in the Madre de Deus prototype. It allowed the virtual reconstruction models to be reimported multiple times, while maintaining all previous editing in the scene. For example, edits such as pre-defined views, hotspot locations, and other visualization settings like illumination could all be maintained even as adjustments to the model were made in another program and re-imported. This enabled the model and the learning experience to develop concurrently. In this way, the platform supports the incorporation of new research findings or adjustments throughout the design of the experience.

However, due to its pre-defined structure, the tool also has some limitations, such as the inability to travel between different model spaces or to turn model layers on and off in a straightforward way. This is a common inhibition among several existing options [3]. In the Madre de Deus project, this greatly complicated the portrayal of different versions of the same space across various time periods and hypotheses. For example, there are several church models that share the same spatial coordinates. Rather than importing them as separate layers or scenes to showcase various iterations of the same space, it was essential to merge the models into a single file and arrange them in spatially counterintuitive manners across three levels to avoid any overlap. This necessitated the creation of a heavy master file that became slow to operate after all the models were linked in, especially in creating long rendering times to bake the illumination settings.

To overcome the temporal challenges, it became necessary to create two visual barriers—vertical and horizontal—to conceal the 16th- and 17th-century models from being visible at incorrect

times (Figure 4). Consequently, rather than allowing visitors to experience different models of the same space from a fixed point, the models had to be spatially separated. As a result, visitors have limited flexibility to customize their own learning experiences of the different spatial evolutions unless they follow the narrative set by the researchers.

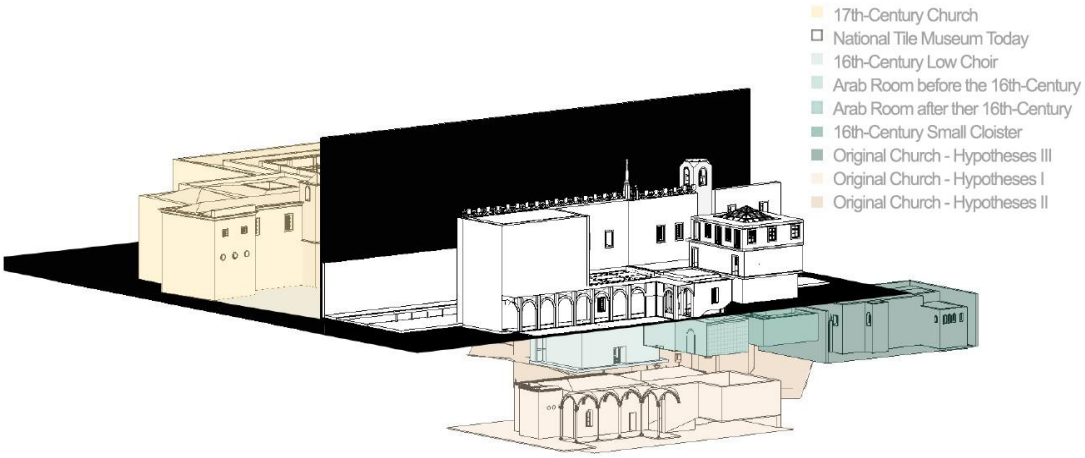



**Figure 4.** Image of the Revit file with all projects and visual barriers. First level: yellow and white; second level: shades of green; third level: shades of orange.

Another limitation of the platform was related to its aesthetic appearance. There are no atmospheric controls other than for the sky, and it is not possible to customize the user interfaces. Unreal Engine, for instance, provides users with dynamic lighting, particle systems, and weather effects along with high-quality sound effects and spatial audio for creating a sense of true immersion.

Although the lack of programming required greatly facilitated this Shapespark prototype, the digital storytelling capacity was consequently reduced by a lack of customization and editability. For example, since the navigation menu that allows visitors to pass from fixed camera points is locationally fixed on the top right of the screen and graphically fixed to appear discrete, it was difficult to integrate this as a central part of an intentional storytelling experience. Rather than follow a sequence of guided instructions or naturally occurring events, visitors need to be aware of their own place within the top right menu to continue following the designed narrative sequence.

In addition, the transition paths between pre-defined camera positions could not be controlled. The tool automatically chooses the shortest path between points, ignoring collisions that normally prevent visitors from passing through geometry in the free navigation mode. This was perhaps the most undesirable aspect of the platform because this means that visitors must pass unnaturally between walls and floors to reach past and present iterations of the space, creating disorienting transition experiences. In this way, the models had to be organized to make smoother transitions between the spaces possible, which is very counterintuitive from a file organization approach. Because of this obstacle, it was necessary to construct a narrative that would allow these transitions to play out in a manner that felt intentional to reach different versions of the spaces. As a result, the only way a visitor can achieve access to the past version of a space is by manually selecting the respective options from the top right menu.

After reviewing this methodology, it is worth noting here that the term "immersive learning experience" has been adopted in this paper instead of other commonly used terms like "virtual tour" or "virtual walkthrough" to emphasize the possible non-linear explorations afforded by the platform. Despite the inevitability of structuring it as a somewhat linear sequential experience with certain hierarchies to better communicate the links of the past and present, physical and virtual, this decision comes from the freedom of the visitor to explore all of the spaces without fixed viewpoints. The visitor can choose to ignore the designers' intended sequence of the experience, despite the unruly transitions it

creates. This was an important consideration since the provision of non-linear experiences has been found to produce better learning outcomes [91] (p. 154).

## 4. Results

The immersive learning experience uses a narrative sequence to guide the visitor through the spaces (Figure 5). Within this model, each space functions as a place for the visitor to be transported back in time to the respective space of the 16th- or 17th-century version of the monastery. The aim of the visit is to present the visitor with diverse hypotheses and their underlying rationale, enabling them to form their own independent opinions.


**Figure 5.** Welcome screen of the final immersive learning prototype. Large violet spheres with an "i" icon are located at the entrance of each space. These provide general information about the room the visitor is about to enter. Small blue spheres with an "eye" icon are located at diverse points of interest such as paintings, objects, architectural features, or other peculiarities. The experience can be accessed through the link: https://ipti.pt/virtual-visit-to-the-monastery-of-madre-de-deus/ (accessed 29 January 2024).

The visit can be explored autonomously or in a more structured manner by following the top right menu for guidance. This top right menu defines the ideal sequence in which to view the spaces, simply due to the transitions necessary. After selecting a menu button, for example, "SMALL CLOISTER 16TH-CENTURY", the visitor is free to navigate around the space to read in greater detail about it through the designated hotspots. Using two types of hotspots, the information is divided into two categories (Figure 6).

Through the "eye" hotspots, one finds more detailed information regarding the relation of these points of interest to the entire configuration of the space, as well as other stories or intangible knowledge. Therefore, the visit accommodates for different types of visitors, either to explore the space in a more general way or, if there is interest, in a more comprehensive way. In these hotspots, information regarding the Poor Clares who lived there has been added. This includes some of dialogues of the nuns found in a chronicle published in 1639 known as *News of the Founding of the Madre de Deus Convent of the Barefoot Religious Women of Lisbon* (*Noticia da Fundação do Convento da Madre de Deos das Religiozas Descalças de Lisboa*) [86]. The chronicle played a crucial role in uncovering clues about the monastery and its daily routines. By integrating conjunctions, tangible evidence,

and oral traditions transmitted within the monastery, the text is an essential source for understanding the relation of daily life within the architecture. Another example of this type of hotspot is information regarding the legend of St. Auta and the healing power of her remains, which were some of the original relics which designated the building as a significant site for pilgrimages. This story is associated with a model of an existing fountain in the space which dates to the 16th century and still occupies its original position in the small cloister. In this way, the tour contains stories about objects of interest or architectural features that were deemed necessary to understand the intangible uses of the space by the former Colettine community.

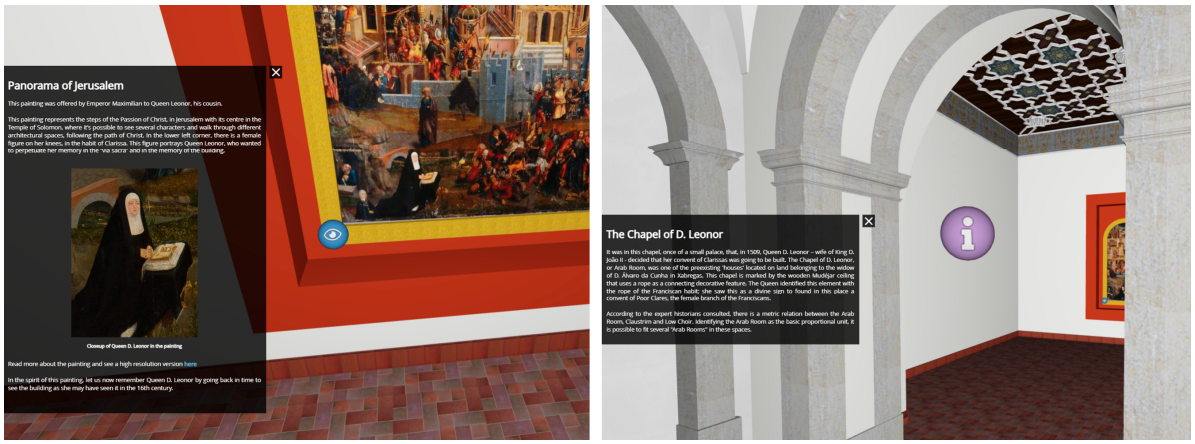



**Figure 6.** Example of two hotspot icons in Shapespark showing detailed information about a painting of Queen Leonor (**left**) and general information about the Chapel of Queen Leonor (**right**).

In addition to the spatial experience which constitutes the immersive experience, paradata of previous research findings are provided within the hotspots, including background information about the spaces, why they were reconstructed in certain ways, and which sources were used to create them. This ensures that the visitor is made transparently aware of how conclusions were made. With access to all essential information used to envision these spaces, visitors can freely question or align with the conducted work. This transparent relationship aims to make the public feel involved in the entire process, fostering a stronger connection with the visit and the building in question The visit employs links to the original historical documents when available online and historical references and page numbers, as well as synopses of conversations with specialists to support the reconstruction hypotheses and allow a transparent comprehension of the modelling decisions. Consequently, the immersive experience illustrates the comprehensive process undertaken throughout the past phase of research, conveying the research journey itself as part of the public's educational experience.

As mentioned above, there was limited control over transitions between the past and present, making for awkward passages between the model's spaces. To compensate for this, a clever narrative strategy had to be utilized to make these transitions feel intentional. This was achieved by creating links through a series of objects or architectural details which exist both in the present museum and the past monastery. Considering the way episodic memory relies on spatial triggers and objects [58–60], the transitions of the past and present in the tour were designed in consideration of the physical building today. In other words, considering that the tour was designed to enhance the museum experience of potential physical visitors, these objects were intended as bridges between the real and virtual and the past and present so that seeing these objects and features in real life would prompt memories of the virtual experiences. Examples of these include the painting of Queen Leonor commissioned for the space during her lifetime which still exists in the space of the Arab Room (Chapel of Queen Leonor) today (Figure 6). After reading about the painting in the present room, the visitor can be transported to the 16th-century version of the space to

see how the Queen transformed the original palace into a monastery. Another example is the church portal which exists today. This current portal appears to match almost precisely with the 16th-century painting of the building's façade. We know, however, from other historic representations that the church portal was replaced in the 19th century. Historians speculate that either the portal is a replica of the painting or that it is original and was simply buried within one of the walls as depicted in a strange irregular excavation drawn in Nepomuceno's plans from the 19th century that coincides perfectly with the dimensions of the portal. Thus, this architectural detail became the vehicle through which visitors could transition from the various hypotheses of the 16th- and 18th-century church. Several of these examples which interweave past and present, physical and digital are highlighted as narrative transitions in Figure 7.

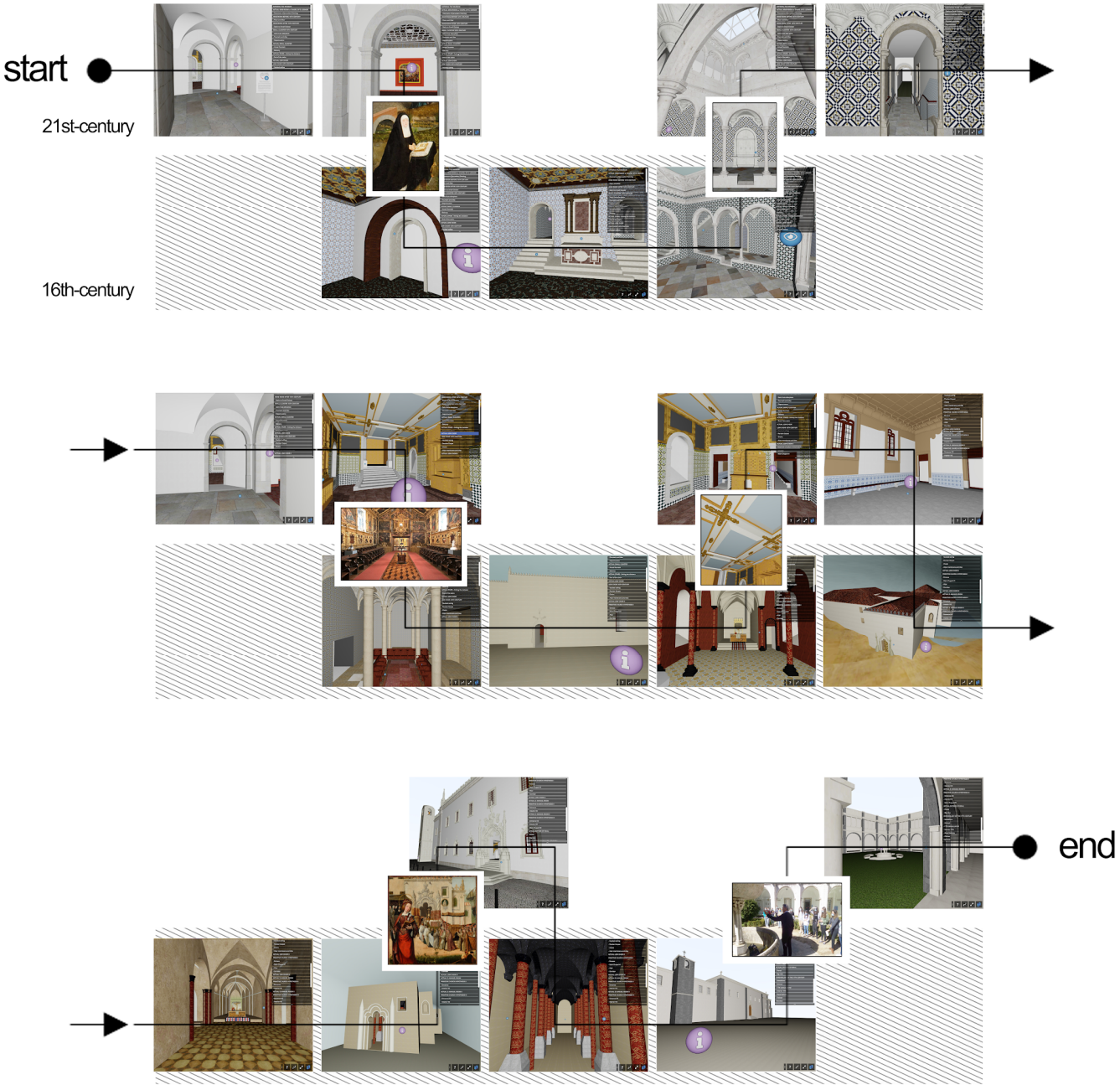



**Figure 7.** Complete narrative sequence of the immersive experience highlighting transitions that interweave past and present, physical and digital.

## 5. Discussion

### *5.1. Defining Limitations of the Previous Virtual Reconstruction Content*

Virtual reconstruction was crucial for bridging the past and present in this case study since it would be impossible to reconcile its fragmentary history with the sparsity of physical evidence alone. What could make sense in writing or in one's imagination might not hold up—both in a figurative and literal sense—until that hypothesis is subject to virtual reconstruction in a 3D modelling environment. This was seen in earlier written hypotheses about the Monastery of Madre de Deus [79,82] that were subject to criticism in past phases of this research [1] (pp. 6223–6225).

Overall, this research has set the stage for future investigations into the complex history of Madre de Deus, with the goal of sharing its story in an educational and engaging manner. However, some limitations of this work adopted from the previous phase of research must be mentioned.

Firstly, the models used were constructed within a limited time frame, and not all spatial adjacencies were explored, especially those related to the main living spaces of the monastery. Although spaces related to religious functions and living quarters are thought to be separate, further comparison with buildings from the same era is needed to develop virtual reconstruction hypotheses for spaces not included in this or the previous research phase. Two examples are the Convent of Nossa Senhora da Conceição in Beja, built by the parents of Queen Leonor, as well as the Convent of Jesus in Setúbal, which, as is noted above, was the first Colettine community in Portugal. These are both Manueline examples which have remained largely intact from the 16th century and are both directly associated with the life of Queen Leonor. These would be crucial to prompt speculation about living spaces like the dormitories, hospice, kitchen, and refectory that would be essential to understanding both the daily life and values of the nuns. Additionally, incorporating digitized paintings or artifacts from the former monastery would encourage deeper exploration of the aesthetic world of the Colettine community. Photogrammetric surveys could be employed to relocate these paintings or specific objects, such as the Samaritan Fountain believed to have once existed on the exterior façade of the monastery. This would establish links beyond the physical museum itself, linking to other culturally significant places.

A second limitation is the fact that there are other equally valid reconstruction hypotheses remaining out of the present research. Different iterations of the ceilings and vaults have so far not been tested for the church and Low Choir. While these hypotheses were beyond the scope of the present research, their eventual inclusion would add an additional layer of narrative and spatial complexity within the existing immersive experience.

Thirdly, due to the time constraints, many details of the spaces of the present building have not been included. Modelling improvements related to the "as-found" model could also be developed to make relevant spatial associations of the present and past and the physical and virtual. In terms of replicating the space today, this would include further articulation of ornate details like the gilded woodcarving used in the altars, ceiling, and painting frames in the space of the Low Choir. The inclusion of painted wall tiles in the D. Manuel Room and a more nuanced depiction of floor patterns of all the spaces would help create more synergy with the existing space. Indeed, visual fidelity in VR experiences has been considered an important aspect for learning effectiveness [49] (pp. 1218–1220) and crucial for VR to connect the public to real sites by triggering episodic memory [56,57].

Within these limitations, however, it would be important to consider that this new information would increase the file size of an already heavy model. As was described in Section 3.2 above, the Shapespark platform works by importing all geometry from a single file, meaning that layers cannot be turned on or off. Additionally, future studies should be aware that visual fidelity comes with numerous costs including to the physical nonhuman environment, equipment costs to operate high-resolution models [2] (pp. 5–6), and operating costs involving subscriptions plans [3].

### *5.2. Responding to Present Challenges of Virtual Heritage Dissemination*

Despite certain challenges related to the transitions between past and present, the Shapespark platform has proved effective in facing several obstacles identified in a recent survey of digital repositories. As discussed previously in Section 1.1, these are the inability to host metadata and to experience temporal differences and the inability to link to archival records or create customizable learning experiences [3]. Shapespark allows users to overcome all these challenges to various degrees, though they are far from ideal. Firstly, incorporating images, videos, text, and hyperlinks to other online archives can be achieved easily, and the visitor can navigate to these provided there is Internet access. This is highly relevant for hosting metadata and paradata and is one of the most successful points of the platform. The hotspots were particularly effective for incorporating the justification for various hypotheses and for creating a narrative sequence for the visitor. It should be mentioned, however, that the platform does not maintain data already associated with the model. Therefore, if an HBIM contains detailed descriptions about modelled elements, these are irretrievable, unlike the programming workarounds that have made data from HBIM retrievable in video game engines [8,9]. Secondly, although experiencing temporal differences cannot be directly overcome, it was possible to use the design of a narrative sequence to direct visitors through the past and present in a sequential manner. This workaround was perhaps the least favorable aspects of the platform due to the awkward transitions it creates when visitors must travel through walls to arrive at spaces in different time periods. Unfortunately, there seems to be no way to overcome this challenge. Thirdly, the ability to differentiate different hotspots according to their purpose for different learning audiences also proves effective for not overburdening the visitor with excess information; however, such learning was limited in terms of reading text, interacting with a model, or viewing a painting or photo. This would be ineffective for testing learning within the environment itself and ineffective for a reward system learning environment commonly employed in video game environments [12] (pp. 87–89).

Shapespark is advantageous due to its minimal learning curve and does not require extensive knowledge of advanced coding languages. While some HTML knowledge is needed to control visual output in hotspots, the tool is user-friendly. Despite its ease of use, it is not widely used for disseminating virtual reconstruction research. However, there are usability compromises, such as the fixed location of the navigation menu, which can disrupt intentional storytelling. Visitors therefore need to be aware of their position in the menu for a seamless experience. Despite this, it works well in both Desktop-VR and Headset-VR without additional setup. Moreover, it comes at a relatively low subscription cost compared to other options [3], which may be desirable when compared with the costs of hiring programming experts.

### *5.3. Responding to Definitions of Authenticity in Virtual Reconstruction Research*

It is important for future research to remember that modern 3D reality capture technologies can create detailed and precise representations, but having these qualities does not necessarily guarantee that visitors will feel a sense of authenticity [39,40]. As Section 2.2 above showed, the debate about authenticity in virtual reconstruction is ongoing and hardly conclusive. There is a diversity of opinions about what it constitutes, and the criteria of scientific value judgments are increasingly prone to debate. As contemporary researchers continue to decipher and tell the past, it is important to acknowledge not only their own historical perspective biases but also the potential contradictory cultural contexts in which historic research is embedded since judgements and criteria of authenticity differ greatly across cultural perspectives [40–42].

The Principles of Seville recommends explicitly showing the "level of accuracy" [37] (p. 6) of a reconstruction project. Shapespark users would face challenges achieving this because it lacks support for various visualization modes. This study did not consider it problematic since the use of different color coding for degrees of accuracy, typical in virtual reconstruction research, [5] (p. 11) can be overly distracting and analytical within

immersive experiences. This factor would create a further distance between the virtual world and the physical space. It was preferred to avoid overt judgments of certainty in such a complex case study like Madre de Deus. Instead, this research relied on the concept of paradata to resolve questions of authenticity, making explicit to the visitor that what they are experiencing has no guaranteed authentic vision of the past.

Regardless of the differing opinions about authenticity, paradata provides one means of declaring authenticity in an open-ended framework. Considering that there are numerous different interpretations of an artifact or historical data possible, paradata provides some measure of assurance and transparency, including how these are defined. According to the London Charter, paradata deals with how a researcher understands and interprets available data involved in a virtual reconstruction project [44] (p. 13). The goal of paradata is to offer others a comprehensive understanding of the objectives, environments, and the reliability of specific visualization techniques used among other factors related to the issues of authenticity [46]. Paradata can take on many different communication forms depending on the specific research project and aims [46]. For an earlier phase of this research, portfolios were used to record this process of decision making. Currently, these notes have become an essential aspect of the research transparency within the immersive learning environment as interactive hotspots describing the spaces or objects before the visitor. The process of subjecting historical inquiry in this case to a variety of different data and the diverse student personalities suggests one way to overcome an overly idyllic or "original" depiction of the past that has dominated notions of authenticity in both heritage and reconstruction approaches that face scrutiny today [40].

### *5.4. Speculating on Immersive Learning for Lost Architectural Heritage*

As discussed in Section 2.3, some researchers suggest that an effective immersive learning experience could leverage interactive elements to elevate a user's levels of perception and cognition through the creation of interactive spatiotemporal connections of objects and spaces [58–60]. In this way, this research has attempted to reconcile paradata and learning in continuity with one another. Consequently, the immersive experience illustrates the comprehensive process undertaken throughout the past phase of research, conveying the research journey itself as part of the public's educational experience. This theoretical stance, however, remains largely untested within this research. To enhance direct public engagement with the past and present in the future, it will be necessary to establish a method for assessing user experience and learning. For this, questionnaires, observations, and interviews provide the most popular empirical options to evaluate the learning outcomes and engagement of virtual heritage [92]. These methods may also serve as an important step in gauging the public's reception of research authenticity [41].

Although an exploration of the immersive learning experience using more sophisticated tools like the video game engines described in Section 1.1 is intended in the future, the narrative technique developed here following the constraints of Shapespark will provide inspiration to future versions regarding the immersive learning strategy. This calls to question the normative assumption that prototyping with the most advanced technologies is always necessary or beneficial. The full freedom to customize virtual experiences according to the will of the designer may not be the best option in all cases. The initial impulse to design without limitation can paradoxically limit narrative creativity. To give the visitor the full freedom to turn on and off layers of the past and present could be ineffectual for an immersive learning strategy geared toward the intangible values of a place because the visitors might miss out on the point being made about why changes occurred the way they did. In this way, associations between the physical place and virtual representation might be lost, limiting the relation between the physical and virtual to a game of spotting differences rather than understanding them.

It has been demonstrated that strategies of narration are consistently identified as the most important aspect for visitor engagement in surveys about digital expositions in museums [60] (p. 14). For this, expanding beyond what was discovered so far in the

hypotheses presented here, future work must incorporate a higher degree of narrative sensitivity and contextualization along with further research into storytelling techniques for virtual heritage learning.

This would imply a further understanding of the historic context of the period and the zone of Xabregas than has been possible thus far. The zone was described in the 16th century as both a village of monks and an anti-city in contrast to the corruption of the city center of Lisbon [14]. This atmosphere, beyond the building itself, is entirely erased by the site's adjacency to a major shipping port today. Such a contextual approach would also entail deeper analysis and scrutiny of the 17th-centry chronicles [86], which while helpful in speculating upon architectural transformations, may in fact have contributed to obscuring the real lived experiences of the nuns who comprised this closed community. For instance, recent historic work on female monastic communities in Portugal between the 16th and 18th century has shown that many women entered such communities forcefully due to family pressures or to escape difficult social and economic conditions [93].

## 6. Conclusions

This immersive learning experience has been constructed as a prototype to garner further public and institutional interest in the project to pursue its advancement to further stages. This experience does not seek to propose a single conclusive reconstruction hypothesis or hypotheses but rather to create an immersive learning experience to allow visitors to have a first-hand experience of what some the spaces may have once been like and to illustrate how different conclusions have so far been reached. This learning experience works by creating associations between the current building and the past, which were previously only evident in fragmentary traces and traditional historic research. The introduction of the data used to visualize the past states of the building alludes to the processes that took place to reach the results and constitutes a key point in its completion, garnering transparency between the museum and the visitor. Therefore, in each space there is information about the history of each room, including specific objects or architectural features, among others, that have contributed to a better understanding of the place.

This research has found that while the constraints of the Shapespark platform were initially felt as a limitation to the storytelling possibilities, these same constraints eventually enabled a creative narrative workaround to allow associations between the physical and virtual and the past and present to be made. Immersive learning can present first-hand experiences of the past in ways that verbal or textual descriptions alone would not suffice in a building such as the Monastery of Madre de Deus, which has undergone major transformations. Instead, one could imagine that having gone through the virtual experience, eventual visitors of the physical space might be able to better imagine the past in situ by associating their virtual experiences with remnants which remain in the physical space. In this way, the immersive experience allows eventual visitors to the physical place to recall their experiences in a spatial way and to associate meanings to objects which are not evident within the physical visit itself.

While the platform was effective at meeting the objectives of this prototype phase of research due to its ease of use and simple integration into the modelling software already in use, it would be difficult to justify it as a long-term solution for this particular case study given the platform's limited user interface and range of educational tools paired with the complex spatiotemporal narrative of Madre de Deus, which involves many overlapping and contradictory hypotheses. For simpler case studies with less complex layers of history, however, the tool would be completely justified when weighed against other comparable online hosting options.

This case study has put into question a universal approach to the narration of lost architectural history. Such an effort appears to be misguided in the contemporary context and would risk overlooking the complex histories, inherent contradictions, and mysteries that come with deciphering the past. It would also overlook the relevance of such studies to the diverse publics who are intended to encounter them. The adaptability of existing

virtual reality programs for immersive learning experiences has much promise but requires a strong narrative basis to convey the past transparently and intentionally. Any narration has unintended consequences and omissions that likewise must be accounted for by the narrators themselves. As shown throughout the literature of this evolving technology, there is much potential but still many questions to answer as to how these tools impact the public's reception of the past and of the physical places under question. In light of such uncertainty, perhaps it would be justified for future research to instead imagine such experiences as construction sites themselves for the continual process of knowledge creation that is inherent to the study and valuation of heritage, rather than fixed records of the past.

Ultimately, the Monastery of Madre de Deus case sits trickily within these debates of this paper. One could say that its complex history defies the possibility of an original or authentic state from which to recover. While parts of the physical building do exist today, most of the spaces have transformed so much over time as to make a comprehensive understanding of the past illegible. Except for disparate fragments and traces of the past recovered from within the building or recorded in texts or paintings, the layer of history from the 16th century is otherwise lost. The building was built upon a pre-existing palace for which we know even less about, followed by almost constant transformation over the centuries that followed. Any attempt to recover this building in any of these spatiotemporal conditions will therefore be faced with an architectural monster [94] composed of Mudéjar, Manueline, Mannerist, Baroque, Joanine, Rococo, and Neo-Manueline elements which all reflect different values and contradictions when weighed against the various forms of life who occupied its walls over time. This extends from the poor lives of the Colettine nuns who made it their home from the 16th to 19th centuries, to the young children who occupied it during its conversion into the Maria Pia Asylum, and to the personalities who occupy the national museum today and their many visitors, foreign and domestic.

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