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VIRTUAL REALITY AS A VERSATILE TOOL FOR RESEARCH, DISSEMINATION AND MEDIATION IN THE HUMANITIES

LA REALIDAD VIRTUAL COMO HERRAMIENTA VERSÁTIL DE INVESTIGACIÓN, DIFUSIÓN Y MEDIACIÓN EN LAS HUMANIDADES

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Highlights:

- Immersive Virtual Reality is used to enhance the digital reconstruction of an 18th-century theatre, by allowing experts to dive into their research topic.
- Virtual Reality (VR) can also be used to disseminate the digital model through the scientific community and beyond while giving access to all kinds of sources that were used to build it.
- A quick survey shows that VR is a powerful tool to share theories and interpretations related to archaeological or historical tri-dimensional data.

Abstract:

The VESPACE project aims to revive an evening of theatre at the *Foire Saint-Germain* in Paris in the 18th century, by recreating spaces, atmospheres and theatrical entertainment in virtual reality. The venues of this fair have disappeared without leaving any archaeological traces, so their digital reconstruction requires fusing many different sources, including the expertise of historians, as well as of historians of theatre and literature. In this article, we present how we have used video game creation tools to enable the use of virtual reality in three key research stages in the human sciences, and particularly, in history or archaeology: preliminary research, scientific dissemination and mediation with the general public. In particular, we detail the methodology used to design a three-dimensional (3D) model that is suitable for both research and virtual reality visualization, meets the standards of scientific work regarding precision and accuracy, and the real-time display requirements. This model becomes an environment in which experts can be immersed within their fields of research and expertise, and thus extract knowledge, reinforcing the model created –through comments, serendipity and new perspectives–, while enabling a multidisciplinary workflow. We also present our tool for annotating and consulting sources, relationships and hypotheses in immersion, called PROUVÉ. This tool is designed to make the virtual reality experience go beyond a simple image and to convey scientific information and theories in the same way an article or a monograph does. Finally, this article offers preliminary feedback on the use of our solutions with three target audiences: the researchers from our team, the broader theatre expert community and the general public.

Keywords: history; research; mediation; theatre; restitution; digital reconstruction

Resumen:

El proyecto VESPACE tiene como objetivo revivir una velada de teatro en la *Foire Saint-Germain* de París en el siglo XVIII, recreando espacios, atmósferas y entretenimiento teatral en realidad virtual. Las sedes de esta feria han desaparecido sin dejar ningún rastro arqueológico, por lo que su reconstrucción digital requiere el uso de muy diversas fuentes: expertos historiadores, así como historiadores del teatro y la literatura. En este artículo presentamos cómo hemos utilizado las herramientas de creación de videojuegos que posibilitan el uso de la realidad virtual en tres etapas clave de la investigación en el área de las humanidades y, particularmente, en historia o arqueología: investigación preliminar, divulgación científica y mediación con el público en general. En particular, detallamos la metodología utilizada para diseñar un modelo tridimensional (3D) que sea adecuado tanto para la investigación como para la visualización mediante realidad virtual, que cumpla con los estándares del trabajo científico en cuanto a precisión y exactitud, y los requisitos de una visualización en tiempo real. Este modelo se convierte en un entorno en el que los expertos pueden sumergirse dentro de sus campos de investigación y especialización, y pueden extraer conocimiento reforzando el

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modelo creado –a través de comentarios, serendipia y nuevas perspectivas–, al tiempo que se posibilita un flujo de trabajo multidisciplinar. También presentamos nuestra herramienta de anotación y consulta de fuentes, relaciones e hipótesis en inmersión, denominada PROUVÉ. Esta herramienta está diseñada para hacer que la experiencia de la realidad virtual vaya más allá de una simple imagen y que transmita información científica, así como teorías, de la misma manera que lo hace un artículo o una monografía. Finalmente, este trabajo aporta comentarios preliminares sobre el uso de nuestras soluciones con tres públicos objetivo: los investigadores de nuestro equipo, la comunidad de expertos en teatro (más amplia) y el público en general.

Palabras clave: historia; investigación; mediación; teatro; restitución; reconstrucción digital

1. Introduction

The use of virtual reality has won over the world of design, industrial and architectural development. Being able to experiment with space or object even before its physical realization is an undeniable asset in these fields (see for example Delgado et al., 2020). In addition, the ability of virtual reality to "immerse" the user in an environment makes it a popular research tool for data visualization, or archaeological restitution. In this discipline, virtual reality permits testing hypotheses through a full-scale simulation while offering natural ease of interaction.

Virtual reality also has an undeniable appeal for the general public: a large majority of which has never had the opportunity to test devices that remain science fiction in some minds. However, the promise of this technology, namely to allow users to project themselves into any environment, naturally makes it a tool with strong mediation potential. At the same time, Ubisoft's productions, and in particular *Assassin's Creed*, highlight the public's enthusiasm and the links that can exist between the world of classic video games and the practice of mediating[1] history and archaeology.

The VESPACE project (Virtual Early-modern Spectacles and Publics, Active and Collaborative Environment), aims to capture the strengths of video games and virtual reality immersion in both research and mediation by proposing to use virtual reality in all stages of what we call the research cycle. This is a collaboration between the University of Nantes (and two of its laboratories: LS2N and LAMO) and Louisiana State University. For the general public, the objective of the project is to allow, in the long term, the immersion of users in an 18th-century Parisian theatrical evening, allowing them to understand the space, the theatrical entertainment and the social customs of that period through interactions with avatars. For the scientific community, it is also a question of sharing a simulation that considers the state of the art of our knowledge of these places of entertainment and the sociabilities of the time, making virtual reality simulations a medium able to approach the intellectual authority of a scientific article or a monograph. These ideas underlie the Seville Principles for Virtual Archaeology (ICOMOS, 2017).

In this article, we will show how we have been able to use virtual reality in the study of our research object (the non-privileged theatres of Paris in the 18th century), in its dissemination, sharing and discussion of this object with our scientific community, and finally as a tool of mediation with the general public. After having presented what we call the research cycle and the historical context of this project, we will review previous works on the use of virtual reality for scientific research and mediation. We will discuss our design methodology, which responds both to the challenges of historical research and to the technological constraints of virtual reality. Next, our approach to historical research in virtual reality will be detailed, focusing in particular on the new tools it requires and the questions it raises. We will then come back to the use of virtual reality as a dissemination tool, focusing on the specific utility we have put in place, called "PROUVÉ", to enable a virtual reality simulation to become a dissemination tool in itself. Finally, we will discuss the use of virtual reality for mediation with the general public. At each stage, we will share our feedback from experiences with nearly 700 people to date.

We, therefore, show how virtual reality can have more and stronger applicability in the world of research in the human sciences, history, archaeology, literature and the fields of heritage and mediation. For this purpose, we will develop in a widespread game design environment to produce an experience suitable for preliminary research, scientific dissemination and mediation for the general public.

1.1. The research cycle in history

In this project, we defined our working methodology as a cycle consisting of three main stages: research production, dissemination and mediation. Each stage of this cycle allows a transition to the next, but also produces information to improve and complete the research production. This first stage, aimed at producing a digital reconstruction, is itself divided into three sub-steps: design of the model itself, review or criticism of this model and capture of information through the immersion of experts in the 3D model, each with feedback loop. The whole process, conceived as an iterative virtuous circle, thus allows the design of a 3D numerical model that draws on feedback from users belonging to the general public, the scientific community and the research team. These three steps are carried out in parallel with the research and interpretation of all the necessary documentation (bibliography, archives, artefacts). Figure 1 represents this research cycle as we define it in this project.

Each of these stages is an opportunity for exchanges between the different disciplines that make up the project, and the specificity of multidisciplinary projects such as VESPACE is to include specialists from various fields who do not always share the same intellectual grounding. Immersive 3D offers the advantage of being

[1] Assassins' Creed Origins thus allows the visit of the game environment, stripped of all its playful dynamics, in the manner of a tourist by giving historical information from the game's scenery elements. One can thus learn more about the pyramids of Egypt for the city of Alexandria by momentarily leaving the narrative framework to take an interest in the historical aspect itself.

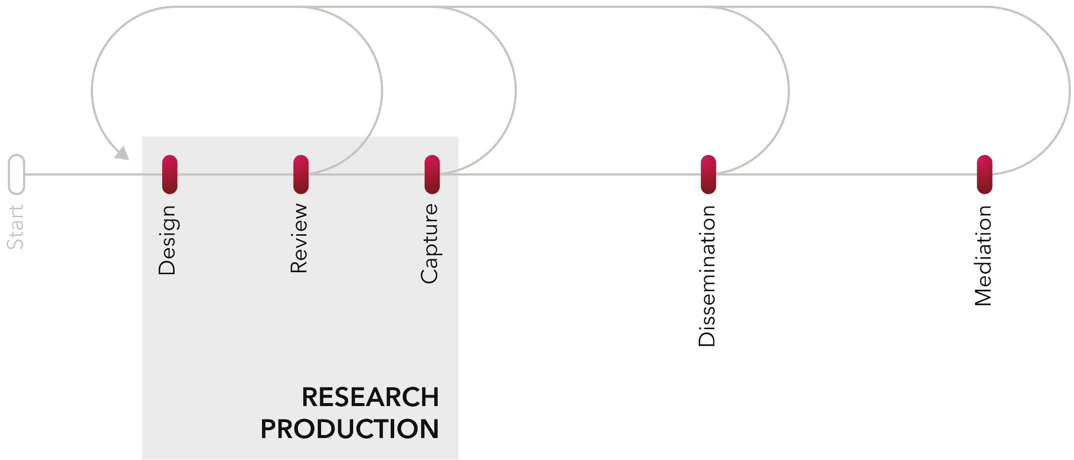

Figure 1: Diagram showing the research cycle as defined in this project.

a media using the visual sense, i.e. the common expression of ideas, objects, spaces or uses. We, therefore, plan to use virtual reality immersion for all the stages of the cycle described above.

1.2. VESPACE historical context

In the 18th-century theatrical landscape of Paris, three institutions dominated the public entertainment landscape: the *Comédie-Française*, the *Opéra* and the *Comédie-Italienne*. Yet, at the fairs held every year at the *Foire Saint-Germain* and the *Foire Saint-Laurent*, many entertainment entrepreneurs bypassed royalty-granted privileges by offering public performances that competed with official institutions. The fairground repertoire was built around the need to circumvent prohibitions and privileges in response to outside world legal pressure. Thus, when fairgrounds were forbidden to use dialogues on stage, plays using only monologues were written. Later, when the Opera claimed to be the sole agent to sing on stage, the audience was then made to sing popular tunes, called vaudevilles, whose lyrics were suspended above the stage. In 1722, actors were even banned, prompting some entrepreneurs to turn to puppets. A privilege could nevertheless be paid for: the payment of a royalty to the Opera allowed the development of a genre typical from the fairs of Paris and which would be a great success: comic opera (Martin, 2002).

These theatres disappeared at the end of the 18th century in favour of Boulevard theatres and institutions (the *Comédie-Française* and the *Opéra*), while the privileges and taxes that were the main reason for the fairs were abolished during the French Revolution. The historiography has also been unkind, often representing these theatres as simple, vulgar and primitive.

The dual historical objective of the VESPACE project is therefore to rehabilitate the historical understanding of these fairground theatres and to study them by simultaneously restoring space, sociabilities and performances. Indeed, while the theatres were destroyed to make way for the urbanization of the current Saint-Germain neighbourhood in Paris or the *Gare de l'Est* (one of Paris' five main train stations), there are still many archival documents describing both the spaces and the social practices that took place there, as well as manuscripts of the plays[2]. Among these archives, a miniature preserved at the Metropolitan Museum of Art in New York, painted in 1763 by Louis-Nicolas van Blarenberghe, shows the inside of a small puppet theatre at the *Foire Saint-Germain* with great detail (Fig. 2). It is indeed possible to distinguish the volume of the space, its decoration, lighting, and especially the costumes and postures of all spectators. This miniature, mounted on a snuffbox, is the basic document of our 3D model, which presents a hypothesis of restitution of the interior of a puppet theatre.

In addition to this image, plans kept at the National Archives make it possible to restore other, larger venues of the *Foire Saint-Germain*. Our work has indeed made it possible to recreate in 3D a 1772 theatre project whose 600-seat capacity alone contradicts the image of street theatres installed on trestles (François, 2018).

2. Virtual reality in research and mediation

2.1. Related work

There is a great deal of work regarding the use of immersive virtual reality for research in history or archaeology. The interest in this technology was indeed already evident at the beginning of the 2000s for the visualization and contextualization of excavation data (Krasnewicz, 2000), but it really became more and more widespread in the 2010s with the use of CAVE-type devices and virtual reality helmets in laboratories like Archéovision[3]. The interfaces allowing researchers to work in these virtual worlds have also been the subject of research, whether in the design phase of the 3D model with haptic interfaces (Christou et al., 2006), or for knowledge management and extraction (Abiven et al., 2018; Gaugne et al., 2014). For this last task, the existence of a system for annotating 3D objects in virtual reality is essential and remains an active research

[2] Many of these were published by CETHEFI, *Centre d'Étude des Théâtres Forains et Italiens*, in Nantes, under the direction of Françoise Rubellin.

[3] To measure the impact of this french laboratory on virtual reality in heritage, see for exemple, the *Virtual Retrospect* collection (Delevoie & Vergnieux, 2015).

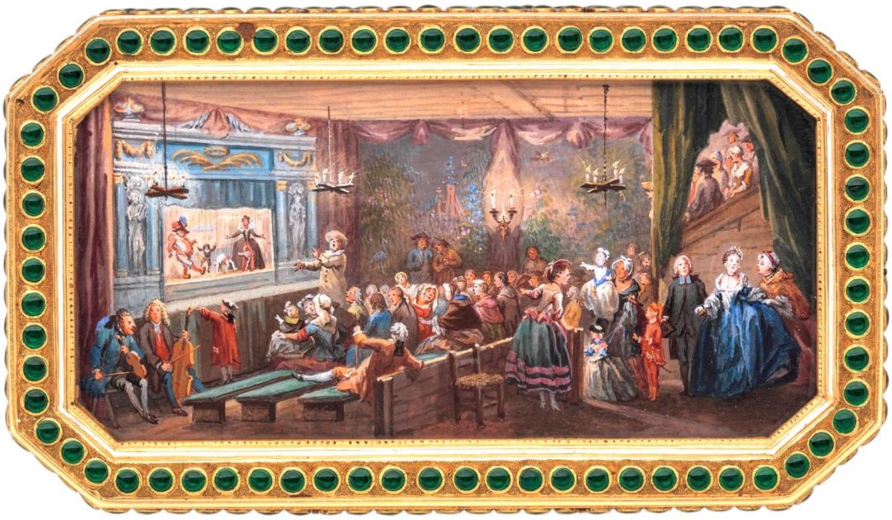

Figure 2: Miniature painted in 1763 by Louis-Nicolas van Blarenberghe showing a small puppet show theatre. MET Museum, New York.

subject, particularly within the French laboratory MAP (*Modèles et simulations pour l'Architecture et le Patrimoine*, UMR 3495) (Manuel, 2016).

This enthusiasm for virtual reality is linked to its ability, according to Laroche (Laroche, 2017), to "capitalize on knowledge and conceptualize information; demonstrate the heritage value of the object of the past; manage the visualization and manipulation of data by knowledge and ensure the possibility of enriching data directly in immersion". Some reviews on the use of virtual reality in heritage projects are pointing out the difficulties inherent to research that is halfway between leisure for the general public, video games and historical restitution because all three categories have different and sometimes contradictory objectives. Indeed, when addressing several audiences with different expectations and modes of access, it is difficult to use a single technical solution that can meet the needs of historical accuracy and engaging narrative, see for example Bruno et al. (2010).

This work often reflects the need for a profound modification of the 3D object between the scientific research phase and the mediation phase with the general public (Rua & Alvito, 2011): either by creating a simpler model or by suppressing information related to research hypotheses. More recent experiments such as Ullastret 3D (Sierra et al., 2017) are in the same vein, reserving immersion devices for the general public, as a final stage of the project, separated from historical or archaeological research. The search for new mediation mechanisms through games or virtual reality is particularly active in the field of virtual museology, allowing visitors to be placed in a virtual situation (Shehade & Stylianou-Lambert, 2020; Barreau et al., 2020). In return, those new ways of engaging with the past, particularly using virtual reality, have been the subject of studies measuring their impact on the general public (Falconer et al., 2020).

To our knowledge, few scientific dissemination experiments, where the 3D object would have the same role as a scientific article, have been carried out. The use of immersive devices allows for exchanges with many researchers (Barreau et al., 2015) but without being open to autonomous exploration, reading and criticism. The work of producing a 3D model for heritage is often disseminated to the scientific community through scientific articles. These articles provide a detailed description of the hypotheses adopted, at the cost, however, of including printed images of the 3D model. All the interest of the third dimension for the reader is thus lost in the process. The use of 3D physical mockups, as shown by Mileto et al. (2021), allows to keep full awareness of the 3D aspect of any artefact for dissemination but with severe sharing possibilities drawbacks.

2.2. Objectives of this research

The previous section showed that the use of virtual reality can be implicated in each stage of the research cycle on a 3D object. Despite this, the variety of virtual reality use-cases implies different tools at different phases of the project cycle. As things stand at present, despite all of these interfaces falling under the generic term "virtual reality", switching from one tool to another involves many reprogramming phases, thus significant time and know-how constraints.

Parallel to these technical considerations is the question of the public's credulity with regard to the immersive experience. The risk is indeed high, since immersion gives the impression of being in space (Kilteni et al., 2012), of confusing a hypothetical virtual reconstruction with reality (Reverdy-Médélice, 2012). It is therefore advisable to give the tools to all users to enable them to measure the gap between the scientific proposal and the vanished historical reality.

The objective of our research is therefore to demonstrate the possibility and usefulness of a unique tool, capable of being used by all audiences, both in the research phase of dissemination and mediation in the humanities. This tool, centred around the immersive experience in virtual reality, would thus be developed from the video game technologies used today for the general public.

3. Design for virtual reality

Projects to restore three-dimensional historical spaces, objects or mechanisms are not new and the tools associated with them are well known. These are, generally and respectively, tools borrowed from architects (Autodesk 3DS Max), animation or video game creators (Autodesk Maya, Blender, ZBrush) or mechanical engineers (CATIA, SolidWorks). The need to be able to view and navigate through the product of these virtual reality models nevertheless adds particular constraints that require adapting the usual 3D restitution workflow without impacting the quality of the model. Just as the question of the origin of a document and its legitimacy is central to the historian's profession, the validity of a 3D model and its "accuracy" with respect to an artefact it represents or a thought it materializes is essential for legitimizing immersive computer-mediated models (ICOMOS, 2017).

3.1. General workflow

3.1.1. Preparation of documentation and database

Even before starting the 3D space modeling, we undertook information gathering work that continued and continues throughout the duration of the project. The data gathered was very diverse in nature (images, plans, biographies, objects, models), requiring a solution that could store, catalogue and search heterogeneous media. To do this, we have implemented a cataloguing solution, based on Dublin Core metadata, called OMEKA[4], and used by heritage institutions to record their collections (Hardesty, 2014).

This solution is based on a basic entity called an *item* that can correspond to a real object, a virtual representation of a real object, a concept, a person, etc. On this *item*, a set of basic metadata can be completed by project-specific metadata allowing a complete description of the object. Omeka is not a relational database out of the box, so we have added the Item Relations plugin which allows defining relationships between the elements of the database by taking as a reference the ontology Friend of a Friend[5].

As a result, and following the digitization or recovery of the archives needed, the database was placed on the project server, allowing consultation by the actors from their respective laboratories and institutions. Not all fields in the database were systematically filled in, a task that would be long and tedious, but we focused on titles, creators, subjects, descriptions and dates. On the other hand, as much as possible, we have defined relationships between the elements of the database: the miniature (Fig. 2) is for example linked to its author Louis-Nicolas van Blarenberghe by the "maker" relationship.

3.1.2. 3D and ambient modelling

The first model of the puppet theatre was made by an architect by analyzing the miniature painted by Blarenberghe. By deconstructing the perspective and according to the height ratios of different elements, it is indeed possible to make hypotheses about the size of the room, its organization, etc. Based on this analysis, the theatre was modelled on Autodesk 3DS Max software (v. 2019), which allows great flexibility in modelling objects. Although the snuffbox we are interested in shows a large part of the room, it was necessary to mobilize other resources (including other miniatures showing similar spaces, plans of puppet theatres, preserved scenes) to obtain a complete model of the room.

This first volumetric modelling then made it possible to model the textures, for which two approaches are possible. The bitmapped textures allow high precision and extremely fine control of the final aspect of the rendering. They also allow the use of scanned materials on real objects to increase the realism of the space. In many cases, applying these textures to objects requires a long phase of UV mapping, which consists of matching each element of a virtual object to an element of a texture image file. Any change in the shape of the object therefore requires a new mapping phase. The procedural textures, on the other hand, are entirely governed by parameters (frequency and colour of a noise, spot dimensions, edge colour,...) and can be applied without the need for a UV mapping phase.

As this is a scientific project where objects, their position and morphology are strongly subject to modification throughout the process, we have therefore favoured the use of procedural textures as much as possible. This approach requires a longer time to make texture parameters, but makes it much easier to modify objects.

Finally, we created photo-realistic lighting inside the scene. The V-Ray rendering engine used for this task (v. 3.4 “Next”) is frequently applied in architectural and animation rendering. As the scene depicted in the miniature is only candlelit, we have modelled as accurately as possible the light power of such candles, their colour and attenuation (Clarke, 2017). Once this modelling is completed, space assumes a degree of realism that allows us to judge the atmosphere (Fig. 3). The integration into the final scene and the rendering gave a good idea of the distortion of the lighting by the miniaturist to make his painting look so vivid in the source document.

Each step of this modelling process was subjected to an intermediate discussion and validation, either by using a set of two-dimensional (2D) images or by using virtual reality immersion, in consultation with project team members from different humanities and engineering fields. Although acoustics is an important factor in early-modern theatres, we decided to confine ourselves to visual and architectural data, leaving it to other research projects to restore an immersive sound environment (Montagud et al., 2020).

3.1.3. Integration in Unity

Real-time visualization and virtual reality solutions from 3DS Max and the V-Ray rendering engine are not suitable for a productive virtual visit at present[6]. To

[4] We used Omeka Classic, version 2.6, which is accessible online: https://omeka.org/classic/. Omeka allows the description of an object by fifteen basic fields of the Dublin Core Element Set. Not all of them were used in this project.

[5] To know more about the FOAF "Friend of a Friend" ontology, please refer to the website of the project: www.foaf-project.org.

[6] Thanks to the V-Ray Ray Tracing mode, the rendering engine is able to render in real time to a virtual reality headset. Nevertheless, the calculation time for global illumination and texture effects by the graphic card is still too long to allow an experiment compatible with the expectations of the project

Figure 3: Restitution of the interior of the puppet theatre. Rendering: VRay + 3DS Max.

enable this use, we were interested in the Unity video game engine, which natively integrates solutions for virtual reality[7]. Indeed, video games rely more and more on realism to immerse players whatever the platform and video game engines, therefore allow quasi-photorealistic rendering. In this sense, Unity is a good tool for recreating the atmosphere of an 18th-century theatre. However, switching from one software to another is not without difficulties, since while the volumetric model itself can be exported simply using the FBX file format, the same cannot be said for lighting and parametric textures. Indeed, to maintain the same quality of photorealistic lighting, Unity's tools are insufficient or require too many resources for real-time rendering. We, therefore, oriented ourselves towards the upstream calculation of all the lighting, a process called baking, and made possible by the fact that the lighting in the puppet theatre is static.

This operation required the UV mapping of all objects in 3DS Max and the calculation of textures and lighting on these objects. The whole system was then integrated into Unity, thus limiting the use of real-time lighting calculations. Only the flames of the candles were programmed in this environment in order to maintain animation during the immersion.

We also used the Steam VR plugin for Unity. This allows the management of the user's movements as well as the controllers of the HTC Vive helmet we use. This plugin is developed specifically for video games but still has some very interesting features for research. It thus allows the user to "teleport" into the virtual space, allowing us to go beyond the limit of 3 m x 3 m allowed by the sensors of our virtual reality system. The project researchers, therefore, have the opportunity to move around the entire model without constraint.

3.2. Constraints and challenges in the use of Unity and virtual reality

As we have seen, the desire to use virtual reality requires new software tools, and therefore conversions and exchange formats that are often synonymous with loss of information. At the moment, it is not possible for Unity's rendering engine to achieve a quality and sharpness of lighting comparable to that allowed by traditional but calculation-intensive Global Illumination methods (and particularly for a project with roughly twenty light sources in a small space). Upstream calculation of the lighting, which requires mapping all objects, has two major disadvantages: on the one hand, the textures produced at the end of this process are only valid for a given configuration of the scene and its lighting (any modification of the luminosity or any displacement of an object requires a new calculation); on the other hand, privileging the procedural textures was intended to limit the use of mapping. Although mapped textures have other advantages, this difficulty has *de facto* imposed a slower pace of model updates.

Virtual reality, and video games engine to mediate virtual reality models, also poses other problems for the design of the model itself. Indeed, while a 3D architectural or scientific design will focus on modelling with the greatest possible accuracy, a real-time oriented design (such as used in VR or video games) will focus on simplifying objects to allow a fluid display. Since we are working on a scientific project in real-time, we are therefore subject to these contradictory injunctions. They are translated numerically by careful control of the number of polygons that make up the virtual objects of the scene. If we take the example of the Corinthian capitals that surround the stage, they are made of multiple leaves and scrolls

researchers. The latest generation graphics cards are, for some, capable of Ray-Tracing in real time for video games, but their power is still too low for the uses that concern us in this article.

[7] Although other development environments, such as Unreal Engine, may offer a higher level of integration with 3DS Max, when the project began our research team had more experience with Unity and it was credited with better integration with the hardware we use.

intertwined with many details. The first version of these capitals counted nearly 25000 polygons per capital, almost as many as the rest of the scene. Given the size of these elements and their reduced visual impact, we have undertaken a drastic reduction in the number of polygons, at the cost of a decrease in the accuracy of their shape.

This decrease poses a problem of breaking the Digital Thread (Cotteleer, Trouton, & Daubner, 2016), the digital link that unites all information from the beginning of the project to its final state. Indeed, by creating a reduced version of our original model for virtual reality, in addition to the technical difficulties it creates, we run the risk of not being able to match the information and lessons from one model to another. It is also problematic that project researchers still only have access to a degraded version of the model, becoming the *de facto* norm. In the model we are operating, this question remains unresolved since only a few details have required substantial modification in order to be displayed in virtual reality and we are in a case of a speculative reconstruction, but in the case of a "virtual museum" type application where the details of a work of art should be carefully restored, hardware, software or user interface solutions should be found.

4. Researching in virtual reality

The design of the model is not an end in itself in our project since we are interested in using the virtual visit of this model for research. Four possibilities seemed essential to us to characterize the potential uses of virtual reality in research for historical restitution:

- Consult *in virtuo* the sources used to complete the model (the subject of the next section);
- Make new discoveries by bringing new points of view;
- Annotate or save comments made during an immersive session;
- Produce new data, natively digital.

4.1. Presence for new discoveries

The feeling of presence defines the feeling of "being there" experienced by participants in a virtual reality experiment (Hvass et al., 2017). In a way, participants feel little difference between perceived virtual space and real space. We have sought to use this sense of presence for research in history and archaeology (Francois et al., 2019) by allowing experts to freely express their curiosity, questions or feelings. During immersion sessions in the space thus recreated, the project's historians were able to experience the points of view from several spaces of the puppet theatre. The view from the last row appeared particularly difficult in the darkness of the theatre, and would be worse in a full house. Moreover, this feeling of presence highlighted the difficulty with which 18th-century women, some wearing a French dress with a diameter of more than one meter, would have moved around in the confined space of a small fairground theatre. This was followed by a search of the archives which revealed the interest of some noblewomen in renting loges in order to sit comfortably. Virtual reality thus makes it possible to open up new problems and provide new answers on a historical subject.

In our opinion, the interest in virtual reality also lies in the possibility of accessing tacit knowledge and information among researchers. Tacit knowledge is defined by Takeuchi and Nonaka (Takeuchi & Nonaka, 2004) as the knowledge of "ideas, intuitions, inspirations" and "beliefs, perceptions, ideals, values, emotions and mental models". It is traditionally expressed through the unconscious or instinctive responses we provide to a given situation or problem. It is mainly this ability to reveal this knowledge that can differentiate virtual reality restitution from 3D restitution visualized on a 2D medium (such as a film, an image, etc.): it involves setting the body in motion (Laubé et al., 2018). In the context of performing arts such as theatre, puppetry or dance, this is particularly important.

During an experiment at the *Institut International de la Marionnette* in Charleville-Mézières (France), we immersed Alban Thierry, actor, puppeteer and playwright in our virtual reality environment, allowing him to explore the puppet theatre stage for which a combination of historical sources and know-how had permitted complete restitution of a period *castelet* (the structure used to play puppets). Even though he had received no instruction in this direction and this was his first virtual reality experience, Alban Thierry naturally took the place of the puppeteer and moved on stage using his hands as if he was really manipulating puppets (Fig. 4). This sequence shows how convincing immersion can be and how much information can be furnished on the use of the restored space, provided that experts can be called in. This is an impressive manifestation of the restitution of tacit knowledge, but other researchers have also shared their knowledge in a less spectacular way, taking physical postures, making comments or recalling knowledge they had never before expressed. Most of the sessions with the researchers are therefore subject to video recording.

4.2. Annotation in virtual reality

The comments made by virtual reality experts only make sense if they are recorded, preserving their tacit knowledge from loss and ensuring the evolution and modification of the model, by incorporating the expertise

Figure 4: Extract from the sequence showing Alban Thierry moving around by mimicking the manipulation of a puppet.

of historians or archaeologists. While different interfaces have been researched to allow annotation in virtual reality (Guerreiro et al., 2014; Clergeaud & Guitton, 2017), we have decided to take a different approach by limiting the use of an additional interface. Indeed, any new interface implies a learning process and an interruption of the kinetic flow that could have had a negative impact on the feeling of presence. Moreover, since these annotations are sometimes tacit knowledge, they do not systematically depend on a conscious process and there was a high risk that researchers would refrain from recording their thoughts.

The path we have followed is therefore that of the complete absence of an interface dedicated to the annotation during the immersion itself. However, we simultaneously record three types of data, provided by the virtual reality headset, during the visit of experts in the environment (Fig. 5):

- Continuous audio of the session through the headset microphone;
- The expert's position in the virtual world, by recording the headset's position in Unity;
- The direction of the expert's gaze, by recording the rotation of the headset in Unity.

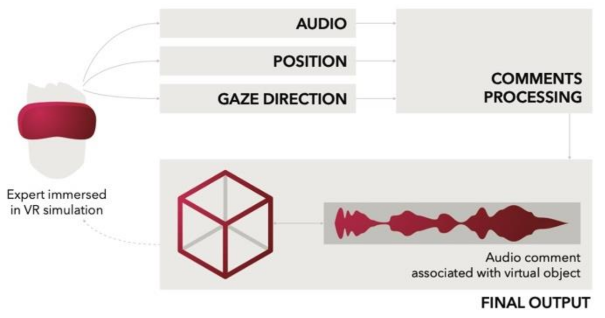

Figure 5: Diagram showing the envisioned process of recording audio comments to link them to objects in the scene.

A visual map of the position and direction of the gaze makes it possible to deduce the objects or spaces that were the subject of the comments recorded in the audio stream. This method has the advantage of ensuring that no information is lost while allowing accumulation of information on spaces as well as on objects, and even on non-spatial concepts. On the other hand, recorder audio requires a significant amount of time for analysis, even if it could possibly be processed automatically.

In the current state of the prototype, all the recorded information is accessible to the user, who can visualize his journey and hear his remarks after completing the experiment. However, the interpretation of these data, to allow the detection of recurring patterns in the movements for example, or for the automatic attribution of comments to objects, still remains to be done through methods of data analysis.

4.3. Natively digital data

The position and direction of the gaze data are natively digital data describing the use of a restored space. While they can be used to understand the objects for which the audio stream comments were intended (see above Section 4.2), it is also possible to carry out analyses to better characterize the uses. From the representation of a user's journey inside the puppet theatre, we can indeed deduce the areas a given user favoured or avoided (Fig. 6). By compiling all of this data, we can also interpret it for all users of our system or certain categories of users.

In the context of the VESPACE project, this information made it possible to highlight the different interests between the project's group of researchers and the general public: researchers are mosty interested in the general architecture of the venue and the points of view (which are an essential feature of the evolution of the architecture of performance venues), while the general public is particularly interested in the organization of the backstage, an aspect that the general public very rarely has the opportunity to see.

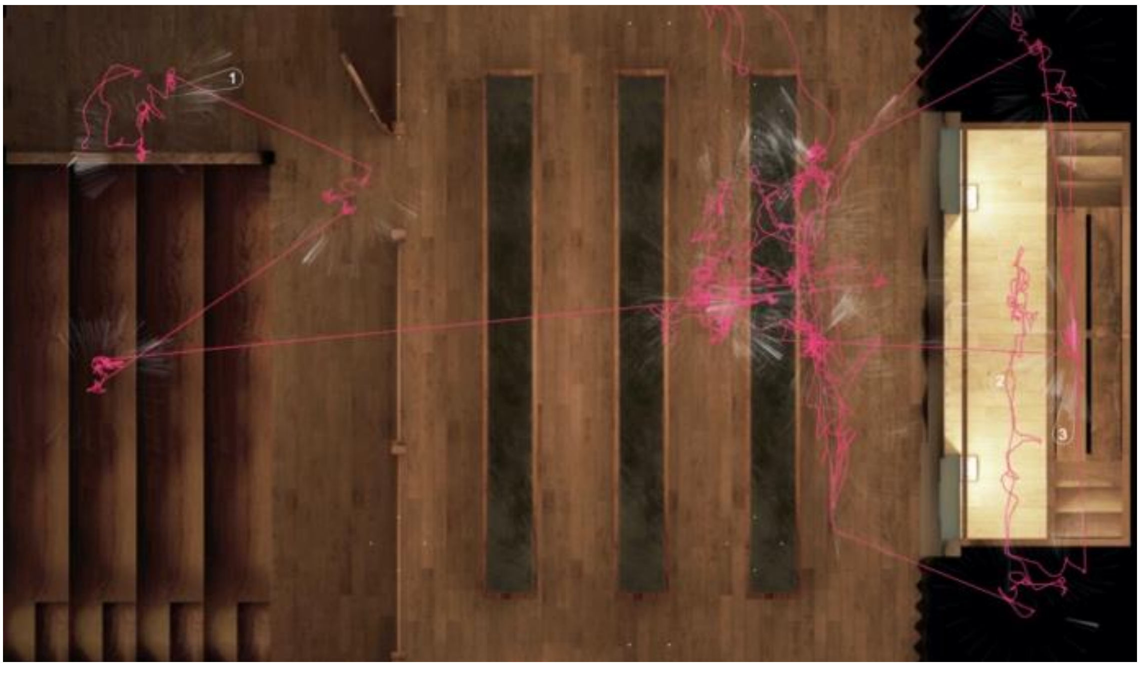

Figure 6: Visualization of the movements of one researcher of the project inside the theatre, viewed from above.

In the long term, and following what is already happening in cognitive sciences, it will therefore be possible to study the behaviour of a virtual spectator confronted with social interactions with virtual avatars within this restored 18th-century space. However, it should be borne in mind that the answers we measure are always those of contemporary women and men, not those of the Enlightenment. This bias is all the more important as we look at the sociabilities for which codes have drastically evolved over the centuries (see for example the evolution of manners guides in space and time as described in Montandon (1994)).

5. Virtual reality for scientific dissemination

Research is disseminated within the scientific community through three main media: articles, conferences and monographs. In this article, we argue that sharing a virtual reality immersion experience is a scientific dissemination tool that could eventually have the same intellectual and institutional value as traditional media. But what is a good scientific dissemination tool? It is above all a support for a theory, thesis or demonstration based on the scientific method. It carries the tools in itself that allow the recipient to judge its context, method and relevance (Mack, 2018). Considering the 3D model, its lighting and uses as the theory we wish to defend, the VESPACE project motivated a design protocol called *Imade Depth* which has been implemented through the PROUVÉ tool in the current iteration of the VR model.

5.1. PROUVÉ, a tool for research dissemination

5.1.1. Basic concepts and software architecture

The PROUVÉ module, (*Extensions Omeka et Unity pour le Patrimoine en Réalité Virtuelle*), aims to visualize information contained in the project's OMEKA database in the virtual reality environment. These are actually a set of extensions for Unity to allow data to be retrieved via the OMEKA REST API, processed and displayed, and a set of extensions for OMEKA to process and display information related to the 3D space and its use. The set was written in C# for Unity extensions, and in PHP respecting the object controller architecture of the OMEKA Zend framework.

The basic concept of our approach is the correspondence between an object in the virtual world (called Virtual Object), for example a wall lamp represented in 3D, and its corresponding image in the database, called Virtual Object Data (thereafter VOD) (cf. Fig. 7). No redundancy of information exists between these two entities, which allows their parallel modification: only a unique identifier added in Unity makes it possible to link the 3D object to its record in the database. We have created a new Element Set (a set of descriptors associated with an *item* type in the OMEKA database) corresponding to these VODs to specify a version of the 3D model and the software that allowed its creation. Each VOD contains at least one title, specifying the object to which it applies, and a description. The latter allows the project scientists to detail the important elements that provide information on the context, method and choices made. It is therefore a first way for the user to visualize the pieces of evidence underlying the hypothesis and the context of what he/she is experiencing in virtual reality.

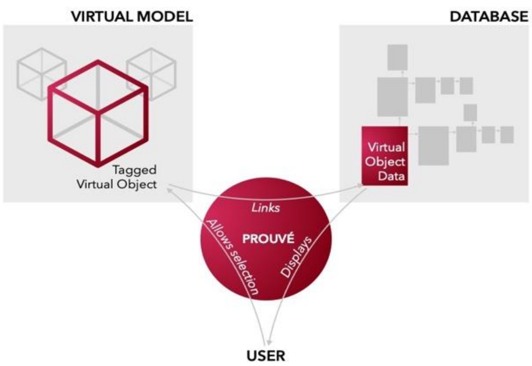

Figure 7: Representation of the general operating principle of the PROUVÉ module.

PROUVÉ also allows users to browse the relational information defined in the OMEKA database using the Friend of a Friend ontology (see above, Section 3.1.1). Indeed, for each VOD, we have linked, thanks to the "source" relationship, all the elements of the database that made it possible to create this object. Typically, for wall lamps, the source of the 3D model is both Blarenberghe's miniature, a set of bibliographic resources on 18th-century theatre lighting –see for example Clarke (2017) or Patte (1782)– and a craftsman[8] re-creating luminaires from that. Not only is this information visible, but it is also recursive, the *item* in the miniature being linked by the "maker" relationship to the *item* "Louis-Nicolas van Blarenberghe". We can see here the interest of the OMEKA database, which permits, thanks to the same generic entity *item*, the description of concepts, 3D objects, existing physical objects, bibliographic references or persons.

The user can consult the information on the objects at his convenience. However, if the user does not interact for a certain period (set to 90 s in the current version[9]), then PROUVÉ will make a suggestion. This suggestion is based on the keywords associated with the elements previously consulted: a user interested in lighting devices will be guided to another element related to lighting.

5.1.2. Interface

Consulting the data associated with a virtual reality database is not a new objective (Bertino, 2006), particularly in the field of heritage. This objective raises two main problems: how to formulate a query to the database and how to display the results. Indeed, the formulation of a query is traditionally done by entering keywords and/or operators to specify search criteria. But this type of interaction, which is common with a keyboard and pointer on a computer, is not very suitable for virtual reality use where text input via a virtual

[8] Régis Mathieu, www.mathieulustrerie.com, is creating chandeliers and re-creates some typical eighteenth-century luminaires, allowing us to have access to an extensive base of photos and references.

[9] Experience shows that the "duration of inactivity" from which a suggestion can be made is deeply linked to the type of user. For the general public, who are less likely to spend time in the system, it may be less than 60 seconds to encourage them to learn about information in space. For researchers used to manipulating the tool, it must be longer than 120 seconds, otherwise the system may conflict with the reflection process.

keyboard is tedious. The display of results and text, on the other hand, is made difficult by the low resolution of virtual reality headsets.

The solution to the first problem is to initiate requests through interactions with the 3D objects of the scene. For any object, it is thus possible to point a virtual laser in its direction and select it by pressing the trigger of the controller. This operation is immediately transformed by PROUVÉ into a query on our database to display the information corresponding to this particular object. From one person to another, thanks to the relationships defined between the items in the database, it is theoretically possible to access any of the information contained in the database. Obviously, as the database accumulated elements (500, today), browsing the entire database using only relations would be ineffective. PROUVÉ's suggestions are a good way to speed up the search process, even if the query mode chosen greatly limits the ease of access to information not related to objects or spaces in the scene.

We have undertaken several experiments in the interface design to visualize the information in the database and relied on previous and ongoing work, for example, Dominic & Robb (2020). Our solution then focused on the information displayed on a virtual screen (a planar surface displaying image and text) anchored to different locations with respect to the user. Three positions were tested: a fixed panel with respect to the position of the player's eyes (like a Head's-Up Display); a fixed panel with respect to the position of the object in the virtual scene (like a museum information card); and finally a fixed panel with respect to the player's left controller (like holding a museum brochure in user's hand). The first position proved bothersome since it does not allow to look at both the object and the associated metadata, the latter hiding the scene in virtual reality and was also tiring for the eyes. The second position has the advantage of being closer to real-life solutions, where it is advisable to approach an object to get more information about it. Unfortunately, it poses difficulties in placing these virtual information cards for objects that are by definition inaccessible (such as ceiling beams) and the metaphor of a card corresponding to an object loses meaning when each card allows potential access to the entire database.

The solution chosen is therefore that of an interface attached to the left controller, while the right controller allows movements and selections. Such a layout allows greater freedom in its position in relation to the user, and therefore greater ease in reading texts. Physically approaching the interface closer or further depending on extending or retracting the left arm, makes it easier to read or observe an image in more detail. Similarly, it is easier to place an iconographic element from the database next to an object in the virtual scene, as it would be to compare a photograph and the object photographed in the real world. The interface itself consists of three separate panels (Fig. 8). The main panel displays the title of the current item and its description, as well as navigation in the database images associated with it, if applicable. At the bottom of this panel, it is possible to browse all the items in the database that are related to the one displayed, by pointing the virtual laser at this part of the interface, the information of the pointed item then replacing the previous one. A second panel, to the right of the first, displays all the metadata contained in the database for a particular item. This retractable panel can be displayed or hidden according to the user's preferences, the information it contains being rather useful for extensive use of the device. Finally, a third panel at the bottom allows navigation: closing the window so that spatial exploration can continue without interface elements (even if some users have shown a preference to simply move the controller behind them), or returning to the previous element when navigating through all the relationships of an object.

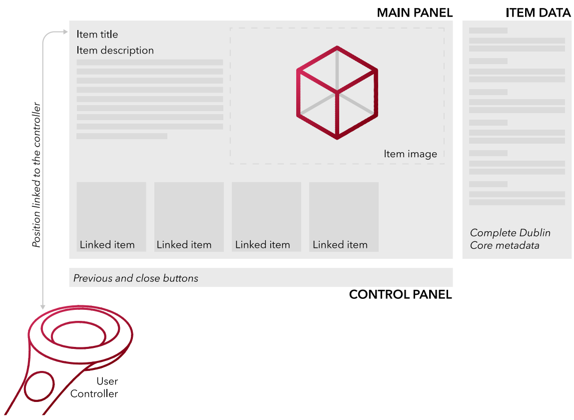

Figure 8: PROUVÉ's interface in virtual reality.

5.1.3. Conduct of the dissemination sessions

In the assumption that the virtual reality program would be executed without any mediator, we have made every effort to allow autonomous use, under conditions similar to those of consulting an article or a monograph. For this reason, the immersion in the puppet theatre is progressive and begins with a presentation of the project and its tools in virtual reality. Like a warm-up campaign or a video game tutorial, the user starts the immersion in a first neutral space that has no connection with the modelled theatre. In this virtual architecture, several explanatory steps allow the user not only to understand the context of the experience, but also to learn how to use the information consultation tools. This short first experiment allows familiarization with the concept of teleportation to move through virtual space, in addition to walking, the discovery of the controls associated with the controllers and the historical and scientific context of the puppet theatre space. It also allows the signature of a contract for data backup, in accordance with the guidelines of the General Data Protection Regulation (GDPR[10]). It is only once all these notions are acquired that the user can enter the puppet theatre. Indeed, despite an increasing adoption by the general public, virtual reality still remains a niche market and, in our experiments, many users had their first experience of virtual reality in the VESPACE model.

[10] Neither the full names of the participants nor any personal data are stored in the project databases. Nevertheless, the sound recording, when activated, could allow for possible identification. We have therefore decided to place ourselves under the guidelines of the GDPR and to allow the consultation and deletion of the data associated with each immersion. The production and recording of telemetric data makes it possible to better understand the uses of this model in a development phase, while allowing users to keep track of the actions undertaken in virtual reality and thus, in turn, to use this virtual reality experiment as a research tool.

Once in the restitution of the eighteenth-century theatre, users are left to move freely around the entire virtual space and to consult information about the objects. Their movements, audio stream and the information consulted are recorded. These records allow the experiment to continue outside virtual reality: PROUVÉ allows recorded telemetry data to be displayed on OMEKA from any computer connected to the Internet. Thus, a traditional computer interface allows user to consult records on movement, the direction of gaze and metadata retrieved.

5.2. Experimental feedback

The complete system was tested at the American Society for Theatre Research's annual meeting in Washington in November 2019 with 18 theatre researchers or practitioners whose average age was between 30 and 39 years. No selection was made prior to participation in this experiment, which was carried out as follows:

- Participants were welcomed in a room where a series of conference posters presented the historical context of the VESPACE project, the restitution work tools, and the objectives in terms of digital and historical research;
- Each participant had to complete and sign an authorization to record information related to his or her immersion, recalling, in particular, the objectives of the project, the data recorded, and the procedures for deleting personal data as required by the GDPR;
- Participants were placed in the virtual reality experiment, accompanied at all times by one of the project's scientific members. The mediator left the user free to interact as he/she wished with the virtual reality device, but answered questions if necessary;
- After the experiment, users were asked to answer a questionnaire reflecting on the quality of the experiment and the PROUVÉ model using the System Usability Scale Questionnaire (Brooke, 1986), to judge their understanding of our approach and finally to measure their enthusiasm for the use of virtual reality in research and/or in their specific field.

The small number of participants in this experiment, as well as the relative similarity of their research interests, does not allow us to draw definitive conclusions about the use of the system in research and research dissemination. The answers to the questions were on a scale of 1 to 5, converted into a 10 points scale for discussion in this article. The answers to the System Usability Scale were aggregated with the appropriate calculation method into a 100 points scale. All the raw results are given in the appendix to this paper (Fig. 9).

This experiment initially makes it possible to evaluate the actual use of this device: indeed, the average time spent in the puppet theatre (and not for the whole experiment) is 8 minutes and 22 s (standard deviation, thereafter s.d., of 2 min 50 s) and users displayed an average of 12 elements from the database (s.d. of 6). Considering that eight objects were selectable and could display their Virtual Object in the database, this reflects not only an interest in the reconstructed objects themselves, but also in the sources that were used to build the restitution.

Most of the system users were new to the use of virtual reality (Q1: 2.5/10 and s.d. of 2.5), which puts the average score on the System Usability Scale (SUS) into perspective (SUS: 73.6/100 and s.d. of 26.5)[11], but reflects difficulties in using the commands related to the virtual reality headset as well as the interface we have designed. Nevertheless, users were in most cases able to access the information they were interested in during the experiment (which is corroborated by the average number of items displayed) (Q2: 8.3/10 s.d. of 2.5) and thus learn more about the space in which they were immersed (Q3: 9.0/10 s.d. of 1.3).

While users felt that viewing documents and sources through PROUVÉ provided a better understanding of the environment and how it was reconstructed (Q6: 7.8/10 s.d. of 2.0, Q7: 7.75/10 s.d. of 2.3), they were nevertheless more doubtful about their ability to discuss the assumptions made during the restitution (Q8: 6.8/10 s.d. of 3.0). This results in a high overall response to the verification question, asking the user if he/she felt space visited was a faithful representation of an 18th-century theatre (Q9: 7.0/10 s.d. of 2.8). For the project's scientists, the model created is plausible but not accurate, since the process leaves much to be hypothesized. The objective of this question was therefore to test, through deliberately misleading wording, whether the precise nature of the model presented had been perceived. A positive answer to this question therefore implies that the hypothetical nature of this virtual reconstruction has not been sufficiently communicated and that it risks being understood as a proven fact. It should be noted, however, that the content of the database was displayed in French to a predominantly English-speaking public, but in many cases with notions in French. Translating the database in English and adding appropriate content is hence a focus point for future developments.

Finally, if users gave an average score of 6.8/10 (Q11, s.d. of 2.3) regarding the value of using virtual reality in academic research before their experiment, this score increased to 8.5/10 (Q12, s.d. of 1.5) after the experiment.

We thus have come to the conclusion that, in its current form, PROUVÉ is able to solicit interest and answer users' questions during a virtual reality immersion. Our prototype has also shown an interest in this technology for research and scientific dissemination. Nevertheless, further additions, modifications and translations of the VODs are to be expected to allow better visualization of the work and the hypotheses themselves.

6. Virtual reality as a mediation tool

We have so far shown the use and interest of virtual reality both in the initial research phase and in the scientific dissemination phase. However, scientific research does not stop at these two levels and includes mediation work. In this section we will return to the initial

[11] The System Usability Scale (SUS) was created by John Brooke to quickly evaluate a wide variety of products, services or interfaces. A good score is traditionally defined as above 75/100, with an average experience of around 68/100. The result obtained is therefore above average, but leaves room for improvement.

claims of the VESPACE project for mediation with the general public: a digital interface to understand the course and social issues of an 18th-century theatrical evening. We will also discuss the use of the current prototype for popularization among a diverse audience.

6.1. VESPACE and mediation with the general public

For the general public, the aim of the project is to make part of the cultural history of the 18th century accessible and enjoyable. The history of fairground theatres, in short, a history of creativity under constraint, responds to contemporary challenges. Moreover, the animation that takes place in the theatre during performances is capable of changing the image of theatrical performances for the general public, built on contemporary standards: in the dark, in silence and in the hushed comfort of an individual seat.

In future developments the VESPACE demonstrator will therefore allow the user, in addition to visiting the space and discovering the associated documentation, to experience social situations typical of the 18th century. In order to place this in serious game logic, the creation of historically realistic avatars and their programming according to the customs of the time is one of the objectives of the project.

In addition to addressing an adult audience, VESPACE also intends to enable schoolchildren in France to immerse themselves in this virtual space. Theatre, the 18th century and digital initiation are indeed on the curriculum of secondary school students. This use, halfway between serious games and the idea of historical reenactment (Morris, 2001), would allow students to experiment with historical situations, to stimulate curiosity about the course and to apply the concepts learned in simulated situations.

Although the VESPACE experiment is now limited to simply allowing the visit of the puppet theatre hall and its backstage area, we wanted to test the public's enthusiasm for this restored space.

6.2. Experience feedback

The general public version of the immersion in puppet theatre was shown at a French national event, the *Fête de la Science*, in its 2018 edition in Nantes and in its 2019 edition in Lyon. During the year between these two editions, the model evolved greatly so that visitors to the 2019 edition were able to visit the theatre's backstage and enjoy more realistic lighting and textures. Nearly 700 people virtually walked the floor of the restored space, the majority of them being children in middle school as part of school outings on the sidelines of the event or accompanied by their parents.

We were not able to administer a questionnaire to all the children who tested our device, but since each of them was accompanied by a member of our team, we were able to capture their feedback in real-time. Experience shows that among children, the appeal of virtual reality is immense: although it is a highly publicized subject, few of them have had the opportunity to test this system. Therefore, it is above all the media rather than its content that has attracted the attention of many of them. This novelty of virtual reality immersion has made it possible to highlight the difficulties for younger people to become familiar with the notion of a virtual environment. Being able to cross a wall or the inability to lean on a virtual step has appeared to some as a very disturbing or even frightening sensation for some users.

Among this same public, we quickly stopped using the PROUVÉ module, which proved unsuitable for this type of mediation. In fact, just as most visitors to a museum visit it superficially without necessarily reading all the information made available, the *Fête de la Science* public wanted above all to have a superficial knowledge of the space for which PROUVÉ and the visualization of each of the sources are not adapted. On the other hand, the discovery of this virtual world aroused great interest so that we were able to discuss in broad terms the fairground theatres, their spatial organization and the social concepts that govern it with each of the participants. The general public particularly appreciated the opportunity to visit the backstage of the puppet theatre, and in particular to explore the environment of the puppeteer. It is indeed a traditionally inaccessible space that arouses great curiosity.

In its current state, VESPACE restitution must therefore be an experience with a mediator capable of guiding the user through the discovery of a plausible historical theatrical environment. Despite the possibility of moving freely in space, virtual reality remains an experience where the user is mostly passive, while the objectives of the project are to make the user active. Future development of the project hence needs to emphasize user engagement through a playable yet informative environment.

7. Discussion and conclusion

The tools we are developing are intended to respond to the problems posed by three audiences with radically different requirements, habits and knowledge. Project researchers, the broader scientific community and the general public have knowledge and know-how that differ in many ways. Thanks to the PROUVÉ module and the implementation of a work method focused on immersive 3D, we were able to demonstrate the feasibility of such a tool and its ability to make all the documentation and hypotheses associated with historical or archaeological restitution accessible to all of these constituencies.

At the same time, we acknowledged the difficulties inherent in the systematic use of the 3D object. The question of representation and access to abstract knowledge, which cannot be based on a 3D model, is even more acute when one is interested in subjects related to social sciences and humanities. Indeed, defining space solely by the elements that structure it is already an important limitation for architects. While linking all representations of an object with its virtual duplicate raises few interface problems, defining modalities of access to intangible aspects of reality remains a challenge. For example, information on the atmosphere, sound or historical context would necessitate the recourse to another type of interface or media. Addressing this issue will require further cooperation between researchers in the humanities, design and user interface professionals and virtual reality experts.

The possibility of using the same tool for researchers, experts or the general public makes it possible to imagine new ways of doing cultural mediation in the digital age. Indeed, it allows all actors to have access, asynchronously, to the sum of knowledge accumulated by all users who have virtually trodden this space. Far from causing know-how in the field of cultural mediation to disappear, virtual reality brings it together to enable visitors to engage with it, whatever their level. Beyond the technical aspects, VESPACE is therefore committed to the development of scientific narratives based on the strengths of virtual reality and digital humanities, allowing new ways of extracting, disseminating and mediating knowledge.

8. Appendix

8.1. Questionnaire

Here are the questions that formed our questionnaire, outside the SUS, which is a default questionnaire:

Q1. How would you rate your familiarity with virtual reality devices? (Completely unfamiliar/Very familiar)

Q2. I was able to access information I was interested in during the experience (Fully disagree/Fully agree)

Q3. I learned about the reconstructed space (Fully disagree/Fully agree)

Q4. I learned about the historical context of the environment (Fully disagree/Fully agree)

Q5. I felt overwhelmed by information (Fully disagree/Fully agree)

Q6. Being able to visualize documents helped me to understand the environment I was in (Fully disagree/Fully agree)

Q7. Being able to visualize documents helped me to understand the reconstruction of the environment (Fully disagree/Fully agree)

Q8. I feel that I have the ability to discuss the hypothesis behind the reconstruction of the environment (Fully disagree/Fully agree)

Q9. I found that this digital reconstruction is a faithful representation of historical reality (Fully disagree/Fully agree)

Q10. Before using this system, how would you rate your feeling about VR simulations in academic research? (Not useful at all/Extremely useful)

Q11. How would you rate the potential for using this system in its current form for academic research? (Very low potential/Extremely high potential)

Q12. How would you rate the potential for using this system in its current form for popularization of academic research? (Very low potential/Extremely high potential)

Q13. How would you rate the potential for using this system in its current form for undergraduate instruction? (Very low potential/Extremely high potential)

Q14. How would you rate the potential for using a system based on the principles of this simulation for your field of research? (Very low potential/Extremely high potential)

Q15. How would you rate the potential for using this system in its current form for undergraduate instruction in your field? (Very low potential/Extremely high potential)

Q16. Would you use a system based on these principles in your field? (Not at all/Absolutely)

8.2. Answers

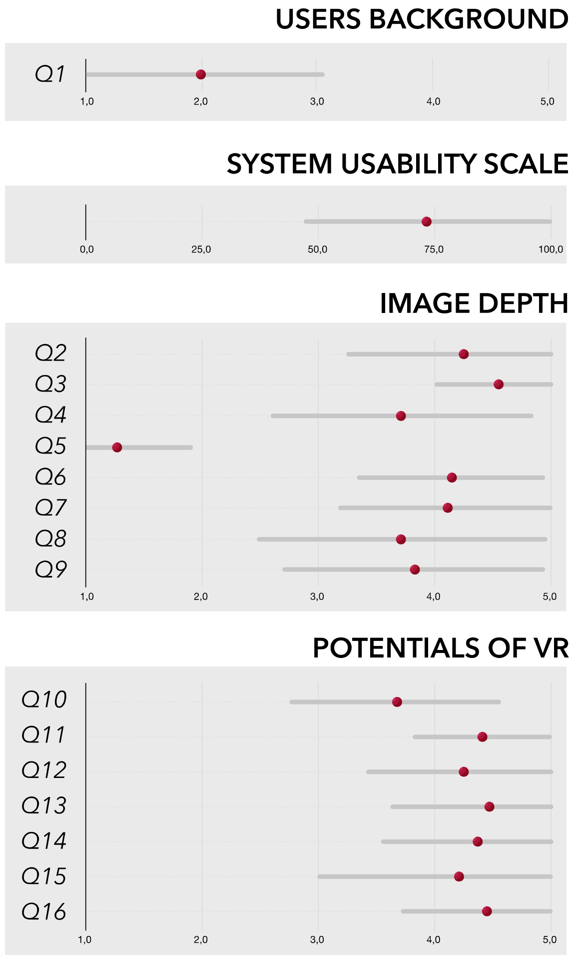

Figure 9: Average answers to the questionnaire.

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