Exploring Fragmented Data: Environments, People and the Senses in Virtual Reality

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Abstract Taking into consideration that archaeologists and historians are today more frequently encouraged to think in terms of digital transduction of historical materials, this chapter focuses on the potentials and pitfalls of 'visualizing' 'recreating' and 're-enacting/experiencing the senses' in Virtual Reality (thereon VR) environments. More precisely, we focus on the very idea of sensory immersion for archaeological enquiry, research, study and dissemination. This chapter draws upon four VR projects at Humlab, Umeå University. The first is an example of using archaeological data for supporting the interpretation process in a Mesolithic site, environment from GIS to an immersive platform. The second is a result of collaborative work with the project ancient dance modern dancers (Slaney et al. 2018) in capturing the intangible art of Roman Pantomime in the theatre of Pompeii on Virtual Reality. The third is the implementation of interactive tools for an immersive study of photogrammetric models of medieval rock-cut settlements while the fourth is an assessment of the implementation of VR Google Earth in teaching ancient topography for undergraduate archaeology students. We show how important and interesting research is made in the process of tool experimentation and tool development.

Keywords Virtual reality · Sensory engagement · Digital craft · Fragmented data

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1 Introduction

Virtual Reality (VR) environments that build around historical and archaeological data have been created and studied for a few decades already. There is a well-established scholarly tradition of reconstructing historical sites in 3D, focusing on estimated architectural and environmental properties of a certain place in time (landscapes, buildings and artefacts), broadly considered as Virtual Archaeology (Forte and Siliotti 1997). The methods and rendering of Virtual Archaeology (approximately from 1990 to early 2000) have been criticised as maintaining static and sanitised depictions of historical space and place without displaying the complexity of archaeological data.

In the mid-2000s, Cyber Archaeology (Forte 2010), has challenged these ocularcentric modes of knowledge production through participatory and interactive design practices. Reflection and cooperative efforts in investigations of sensory engagement with space, architecture and artefacts of the past have the potential to generate new knowledge (Forte 2010). Cyber Archaeology promises, through interactive virtual immersion, to operate as a testbed for linking archaeological information to intangible data about the past. Inspired by the theoretical premises of cyber archaeological inquiries, this chapter advocates Virtual Reality as a participatory, interactive method with great potential, and ought to be addressed with a sensibility to pedagogy and digital infrastructure for optimal results.

This chapter offers an in-depth analysis of the practice of virtual model building, as well as potential scholarly and pedagogical benefits based on four case studies. We argue that VR, as infrastructure, has the potential to engage researchers and students in direct interaction with multiple datasets and may help them reflect on sites that are otherwise inaccessible and remote. Such an enterprise requires transparency throughout the process of annotation and interpretation of data. Beyond the visual component of alternative (e.g. augmented, VR, Mixed) realities, an analysis of already fragmented datasets can be mediated through a sensorial engagement and this process is generative of both knowledge about the past and the discipline of archaeology itself.

For the purpose of this chapter, we have chosen to discuss four examples thematically from the perspectives of fragmented data about past people/spaces and the sensory properties of the VR prototypes. These prototypes were deliverables from research projects that have been carried out at Humlab, Umeå University, in 2017–2018, and were supported by a community of students, researchers and developers. All the described prototypes have been developed using an HTC Vive set, with a field of view of 110°, resolution of 1080 × 1200 pixels, refresh rate 90 Hz, audio output with headphones, positional tracking and head tracking. The prototypes were implemented through a game engine technology, Unity, a cross-platform development software mainly used for games, digital art and entertainment.[1] Unity tends

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[1] https://unity.com/.

to support a wide range of file formats, making it particularly suitable for experimentations and data import from other applications (for example from GIS software, photogrammetry models or mocap data).

Our inquiry encompasses the analysis of an immersive interactive visualisation of the data from a multiproxy investigation of a Mesolithic dwelling in Northern Sweden, where a palaeoenvironmental reconstruction of the VR environment was completed by applying a reflexive approach (Berggren et al. 2015; Hodder 2000). The second case study is a motion-capture experimental reproduction of roman pantomime that involves the exploration of the sense of self-movement (Slaney et al. 2018). The third example presents a workflow for importing a photogrammetric model of a rock-cut settlement in Unity and implementing customised drawing tools, crucial for the analysis of the rock surface in VR. Finally, we will evaluate the use of VR in undergraduate archaeology classes as a medium for exploring space of a multi-layered urban centre.

With this chapter, we aim to show how the process of building and displaying VR models has pedagogical value and how the potential of VR prototypes to mediate sensory information helps reflect on data at a deeper level. By doing so, we further feedback on how customised tools are created to interact with the models function and recommend possible solutions for technical issues or desirable future improvements.

2 Broken Data and Multivocality

Potentials of experiential learning in VR environments have been investigated in various disciplines, including both humanities and natural sciences. The development of VR prototypes focusing on educational aspects has triggered a broad theoretical reflection over pedagogical prospects of immersive environments (Fowler 2015). In archaeology and ancient history, VR has been used mostly for ‘time travels’, i.e. the re-enactment of ancient scenarios in which the user can interact with avatars or objects. These models are certainly interesting for communication as they generate a fully reconstructed past setting in which the visitor is projected, with little or no access to metadata and paradata.

Nevertheless, the creation of any VR prototype that relies on archaeological/historical data should be correlated to the theoretical reflection over the way raw information is transduced in virtual environments. Since its early applications, it has been clear that ‘virtual reality is geographically, culturally and temporally situated as much as the context that it aims at visualizing’ (Brody 1991), and therefore depends on the archaeological set of data available at the moment of the creation of the models, the theoretical standpoint of the developers and the technology used. Examining the creation of a VR prototype, we can gain an insight into the process of constructing archaeological interpretation and use the digital platform as a support for the exegesis of raw datasets.

A lot has been written on archaeological documentation and data collection including digital and analogue methods currently used by archaeologists to register and store observations on traces that are, most of the time, ephemeral. The majority of archaeological recording is done in the field, where the observation of features and objects demands a specific set of competences. Data collection is based on the assumption that the researcher deconstructs the material trace in distinct sets of information as complete and as accurate as possible. Archaeological data necessarily comprise gaps and uncertainty, due to the difficulty of capturing all aspects of material remains. In fact, the documentation of archaeological evidence is made more difficult by the fact that all objects and traces are subject to a multitude of interactions, as part of a lively ecological system. In order to represent the complexity of the interplay human environment, archaeologists usually divide up the record into proxies that can be measured individually, such as the case of various types of artefacts (ceramics, lithics), soil geochemistry, pollen analysis, etc. According to Caraher, this forced simplification and segmentation of the archaeological record relies, at its core, on a meticulous observation that requires time and dedication, the so-called ‘slow archaeology’ (Caraher 2015).

Sets of data concerning geographical/environmental and chronological attributes of sites can be acquired by means of standardised practices. Digitised or digital data can then be combined and intertwined in a VR environment, where criteria for visualisation are mediated by the judgement of researchers and programmers.

Due to the high variability of hardware and software used for visualising and recreating the past, there are no clear guidelines for the rendering of models but rather some collections of broad principles that provide a benchmark for each community of practice (that is, for example, the case of the London charter). In this context, a lot of choice about prototyping procedures and display of information is left to the specialists.

For instance, the geographical dimension of a site/landscape can be reproduced partially or highlight prominent features, according to the specific research goals and available information. In our case study, creating an interactive prototype of rock-cut sites, the accurate representation of the internal surface of the excavated room was considered a relevant landmark, while the location of the site in its original landscape was not essential. The choice of representing only part of the original environment resulted in a carved chamber floating in a space without geographical connotations in which the user is demanded to focus on the carved features inside the cave rather than the eternal context.

Another example of a rendering of ecological interactions in a complex space is the creation of a VR prototype for the study of a dwelling discovered in Lillsjön, Angermånland, excavated in 2010/2012 by a team of researchers and students from Umeå University, consisting of a pit house dated to mid-late Mesolithic (7200-5800 BP) BC. The site was excavated following a grid of small test pits covering a total area of 0.4 ha and documenting archaeological features and findings mostly on notes and paper drawings. In order to reconstruct the Mesolithic palaeoenvironment context of the area, the excavators collected samples for macrofossils, pollen sequences and soil geochemistry. The dataset resulting after excavation and laboratory analysis was multifaceted, including different types of information in various formats and scales:

- More than 850 soil samples (analysed for phosphate, elemental composition and organic content);
- Position and amount of findings (bones and lithics, characterised according to raw materials and typology);
- Features and C14-dated samples;
- Core samples for pollen analysis.

In May 2016, the digitalisation and systematisation of data from the excavation in Lillsjon were carried out using Esri ArcScene (the use of tridimensional mapping platforms—particularly GIS—for the study of archaeological sites is becoming a common practice amongst archaeologists; Dell'Unto 2014; Dell'Unto et al. 2016). The information gathered during the excavation was stored in a geodatabase connected to 3D features corresponding to the excavated trenches. Height values (z) of features and 14C-dated samples were interpolated in order to reconstruct the various phases and, in particular, the earliest Mesolithic tramping levels. The dataset modelled in ArcScene included a high-definition set of palaeoenvironmental proxy, but while the spatial analysis performed through GIS could highlight important information and link different datasets, ArcScene could not be used to render the delicate balance of ancient soils and vegetation. Paleoecological information was implemented in Unity, developing a VR prototype that could be used to visualise artefacts, features and environmental data.

The 3D GIS, primarily designed for quantitative analysis, was used to interpolate the trampling level dated to the earliest Mesolithic phase and associate that to various features (postholes, hearths and waste pits). The geographic attributes of the scene were created importing both the original terrain model and the interpolated surfaces that represented the prehistoric trampling levels. The vegetation was reconstructed thanks to macrofossils and pollen sequence, combined together with palaeogeomorphology and soil properties. The features documented during the excavation were represented on the interpolated surface, and flagged using floating tags (Fig. 1).

In this case, the reconstruction of the ecological context from various proxies is based on the establishment of links and correspondence between distinct datasets rendered through the immersive environment (Buckland et al. 2018). The VR scene was used as a tool for knowledge production, offering a peculiar space for exploring connections and overlapping between various branches of information. The data-driven VR prototype facilitated the visualisation of interactions between different data sources, supporting an experience-based interpretative process. In these terms, the design of a VR prototype is the product of a reflexive and collaborative practice, based on a scrupulous monitoring and the development of specific skills. Modelling becomes a digital craft, a slow process in which segments of information are interlaced to constitute a wider knowledge network (Goodrick and Earl 2004).

The reconstruction of the Mesolithic dwelling structure was approached as a participative workshop. The structure of the dwelling was suggested according to literature and ethnoarchaeological comparisons (Bergman et al. 2004; Olofsson 2003). Post-holes documented during the excavation were marked and used as a

Fig. 1 The VR prototype of a Mesolithic dwelling site in northern Sweden. The two images represent two moments of the making: importing and flagging features from 3D GIS to Unity and reconstructing the ancient vegetation according to paleoecological data

reference to propose possible structural solutions for the shelter. The position of the posts was tested and discussed as a digital experimental workshop involving several researchers that could experience the virtual scene both with the headset and projected on a screen (Dunn and Woolford 2012). The VR prototype fulfilled its potential of rendering the analytical process, from the visualisation of archaeological data, studded with gaps and uncertainties, to the complicated task of formulating interpretative hypotheses on a shifting ground.

Transparency is a crucial attribute of VR prototypes, fundamental in order to verify and validate the models. In fact, defined codes can be applied to feature metadata and paradata, acknowledge the source of information and recall the interpretative process. This is the case, for example, of the extended matrix, a formal language that uses the stratigraphic approach to create a taxonomic system for virtual reconstruction (Demetrescu 2015; Demetrescu and Fanini 2017). An open rendering of immersive environments with the integration of interactive tools for browsing the making of virtual models can trigger discussion and collaborative practice, as shown by reconstruction of the house of Caecilius Iucundus within the Swedish Pompeii project (Nicolò Dell'Unto et al. 2013; Demetrescu et al. 2016), the 3D repository and model-building protocol of the MayaArch3D project (Von Schwerin et al. 2013) or the Second Life model of Çatalhöyük (Morgan 2009).

Both raw data and virtual models represent the consecutive steps of an archaeological investigation: from raw data to narrative reconstructions (Pietroni et al. 2005). Stages in the interpretation process of our Mesolithic dwelling were rendered creating a distinct user interface, with the possibility to switch from one visualisation to another. In each scene, geographical landmarks (e.g. the lake) were left unaltered while the models of the dwelling area were modified. In the first scene, data from the excavation are represented fragmented, correlated by tags and symbols that specify the field description of the evidence. In this interface, features are represented as blank shapes on the interpolated surface. The graphic choice highlights gaps and discontinuity within the dataset offering at the same time a projection of the original paper drawings and the 3D GIS visualisation. In the second scenario, a simple rendering of the dwelling structure displays the result of the experimental digital workshop. The reconstruction is intentionally synthetic; the poles are rendered as simple geometries and can be moved and rearranged as the hypothesis is modified. The third scene aims at a rather phenomenological experience of the reconstructed environment, with the soft light of the dusk lightened up by a fire rustling in the shelter. The three settings display different stages of the embodied interaction as parallel and complementary narratives.

The re-enactment of past intangible characters can be mediated by using immersive platforms for experimenting avatar implementation. For the project Digitizing Ancient Pantomime, the goal was to create a virtual environment of a pantomime performance, using the language that describes movement and the relevant libretti to create 3D avatars of dancers. The process of building an ancient environment (roman) to accommodate the avatar of a dancer required a much simpler solution. 3D Models of Roman and Greek amphitheatres can be found online, and are easy and cheap to purchase.[2] The research team decided to use a 3D photo-realistic representation of the theatre of Pompeii that could be openly accessible and reused in Sketchfab. We further embedded different weather and light conditions as options in our prototype. Darkness, light, torches and even rain were options by which the user could experience a pantomime performance. As pointed out by Papadopoulos and Earl (2014), illumination can have an impact on the perception of a reconstructed environment, enabling a better understanding of the space and inducing different experiences (Boyce2014; Parisinou 2007). Instead of recreating a specific environment, the attention was placed on building a number of conditions that could correspond to environmental properties.

For the purpose of recording the dancers, we collaborated with members of the Lausanne academy of dance *Les Marchepieds*, and used the 'Black Box', an isolated motion capture laboratory in the ground floor of the Sliperiet facility at Umeå University. In a space of approximately 20 m^2 (4 × 5 m), we positioned a wooden flooring (3 × 3 m), and 12–15 cameras close to the ceiling of the Black Box. The dancers slipped into motion sensor costumes and dancing movements were recorded with the help of the motion capture software (OptiTrack 13 W) and using Motive as interface software. Motive offered several different options for visualisation including:

- an ungendered avatar, that could be characterised using male or female default models; and
- motion tracking avatars with strings that display direction and velocity of the motion capture.

The technological complexities of recording the dancers and their bodies in full are covered extensively in Slaney et al. (2018). For example, custom sensors on the costume proved too few to capture dancing movements accurately and in turn, the dancers felt constrained by technology. Constructing an appropriate avatar was a gradual process. The final avatar used was a synthesis of disparate gender and age features: a conventional female face on a young/early teenager male body with an olive skin complexion and African hair. The reason for the combination of these aesthetic elements was to reflect that professional dance training started from a young age in antiquity (Libanius, *Oration* 64, cf. Slaney et al. 2018). When envisaging the final deliverable, we wanted to break the shackles of dominant thinking about people in the Roman Empire: recent discussions of representation and reception dictate that we see entertainers as slaves or freedmen that may have arrived there from all points of the empire (Fig. 2).

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[2] At the time when the article was written the available online repositories were: https://3dmdb.com/en/3d-models/amphitheater/; https://sketchfab.com/tags/amphitheater; https://www.cgtrader.com/3d-models/amphitheatre.

Fig. 2 The virtual reality environment and avatar in the digitizing ancient pantomime project

3 Critical Senses

As argued in the previous paragraph, the deduction of intangible attributes from fragmentary tangible evidence is the most challenging responsibility of historical disciplines. The use of VR platforms supports the visualisation of the interpretative process, bolstering the digital representation of links and interactions amongst physical findings. Involving various degrees of multisensorial engagement, VR relies on sensory feedback for generating a user-centred analysis of the models.

A scholarly exploration of sensory experience may provide gateways to both the mind and the body; it mediates cultural values between the individual and the social world (Betts 2011; Favro 1996; Witmore 2006). By situating an enactment into the sensory sphere, the user has the possibility to learn by experiencing, and reflect on a distant and intangible past.

Gaps and ambivalence encountered through a sensorial examination of virtual models could also represent a key for comprehension of a complex set of data. As Tarr and Warren pointed out ‘the critical element provided by virtual reality is the ability to break the laws of optics and physics, or to disconnect physical reality as specified by a subject’s body senses from the world he/she is seeing’ (Tarr and Warren 2002, 1090). In fact, new knowledge is generated through the virtual experience of breaking the laws of physics: something that happens and our brain perceives as odd or ‘unnatural’. Brain responses to VR computer interface have been studied especially with regard to medical rehabilitation and specific treatments. Understanding sensorial responses to VR models helps maximise the potential of information transfer within immersive environments. According to Dalgarno and Lee’s model of learning, users develop a sense of presence in an immersive environment through a realistic representation of space, a consistency of the objects’ behaviour and audio mapping. These features enable the sense of presence, defined as an ‘act of selection between two hypotheses’ (e.g. I am here or there, (Slater 2002, 435). Interaction as co-presence is then achieved through control of objects’ behaviours in the virtual environment, embodied action and communication (Dalgarno and Lee 2010).

According to these models, the cognitive ability of the observer is influenced by the hardware performance. Visuals and tracking accuracy deeply influence users’ responses and ecological validity, meaning that an observation made in the virtual environment remains valid in the real world (Sjölie 2011). For example, the view is significantly enhanced when coupled with head tracking.

As argued, an important feature to consider when re-constructing a sense of presence in VR is audio mapping. Within Digitizing Roman Pantomime, we adopted a methodological approach, termed *synaesthetic prototyping* (Foka and Arvidsson 2016). Inspired by post-processual thinking in archaeology, the proposed approach aimed at turning attention from sensory accuracy to experiential analogy. While there was a lack of tangible evidence about the sonic experience of a roman pantomime dance, we enabled multiple interpretations possible of any sensory experience (Hodder and Hutson 2003) and to treat sensory data, in this case, sound, as materially situated in both space and time (Hodder 2012).

While there have been studies on the acoustics of the theatre of Pompeii and others (Berardi et al. 2016), as well as music in antiquity (e.g. Armand D’Angour’s study of Ancient Greek music), we unfortunately had none of these audio materials at our disposal. With all our sound settings (reverberation, impact, etc.) set to analogue, we aimed for the sonic impression of a pre-industrial setting. We then divided natural sounds (birds, rain, etc.) from artificial (human-generated) sounds, and as our environment took different configurations we created soundscapes by analogy. This method recognises that information data will always be incomplete and gaps therefore need to be filled imaginatively. Nevertheless, even the sound reconstruction can be made explicit by introducing different tracks and the relative metadata (Bruno et al. 2010). For example, we experimented with drum sound samples and rhythms from around the Mediterranean (e.g. 9/8) in order to examine phenomenal patterns of communal approval (if any), thus renegotiating social and ethnic diversity in the Roman Empire.

Contemplating sounds was a lesson for all of us as researchers, which we wished to pass onto our students. During our course on Heritage Implementations we presented the prototype to discuss how sounds and their meanings are considered as shaped by the cultural, economic, and political contexts in which they are produced and heard (Ihde 1970; Smith 2001). Indeed, sound studies have been referred to as ‘the interdisciplinary ferment in the human sciences that takes sound as its analytical point of departure or arrival. By analysing both sonic practices and the discourses and institutions that describe them, it re-describes what sound does in the human world, and what humans do in the sonic world’ (Sterne 2012, 2).

The actual aspect of the VR environment also plays an important role for generating a captivating scene. In order to trigger brain responses to the virtual environment and enhance the immersive feeling, archaeological VR models have been designed to be more and more appealing, through improving the acquiring techniques, the generation of models and textures (Slater 2009). Despite the exceptional quality of some renderings, a few unavoidable flaws occur in the transliteration of archaeological objects into virtual models. For example, some inconsistencies can arise when juxtaposing the represented place of the immersive environment with the real space (the room) in which the user is situated. Most of the time, the scene represented in the VR model does not match the physical environment in which the user is located. While the digital landscape is defined by spatial attributes that can be explored, users' motion is usually limited by material constraints, such as walls, furniture or the position of the tracking devices.

A main idiosyncrasy when dealing with material evidence in a virtual space is the lack of materiality, a physical texture to handle. In archaeology, the understanding of sedimentary record and artefacts is largely achieved through touch, while in a VR environment the loss of solidity could affect the immersive feeling (Allison 2008). The implementation of interactive touching features could represent an important goal for developing historical and pedagogical VR. At the current state, specific hardware for handling virtual objects are being developed, such as haptic gloves, but standard solutions for regular users are not yet available.

Particularly interesting to enhance synergic and immersive feelings is the design of an interactive apparatus to engage with the model. A VR prototype can be implemented with a number of tools and widgets that allow the user to perform predefined actions in the defined space. The architecture of these tools correspond to the needs and aims of the designers and respond to precise research questions. While VR software does not incorporate specific tools, quite a lot of freedom is left to programmers to implement the interactions according to the use.

An illustrative example of the advantages of VR in rendering immersive spaces can be found in the study and documentation of rock-cut chambers, caves or rock shelters: spaces opening from a vertical cliff and characterised by engraved features. The documentation and interpretation of these sites begin with a meticulous mapping of the inner rock surface in order to identify tool marks and carved features, crucial for understanding the use and transformation of the space. Rock-cut sites do not usually incorporate thick sediment deposits and therefore excavations in these specific sites are almost impossible. Consequently, data collection and interpretation are mostly done by mapping carving techniques and discontinuities on the rocky surface. The entire characterisation of the stone walls, including volumes and position of the niches, is hardly described through a two-dimensional mapping system and requires a tridimensional representation. The inside perspective, necessary for observing the carved surfaces, could be recreated thanks to the immersive potential of VR environments, establishing a workflow for importing photogrammetric models and implementing interactive tools (Fig. 3).

The experiment was carried out on a medieval rock-cut settlement situated in the Puy de Dôme, Auvergne, France. The site is located in the district of Murol and consists of eight rooms arranged on two floors and carved in a volcanic cliff. The dwelling is nowadays located in a dense woodland with the entrance of the lowest caves lying a few metres above the ground, making the access to the site extremely

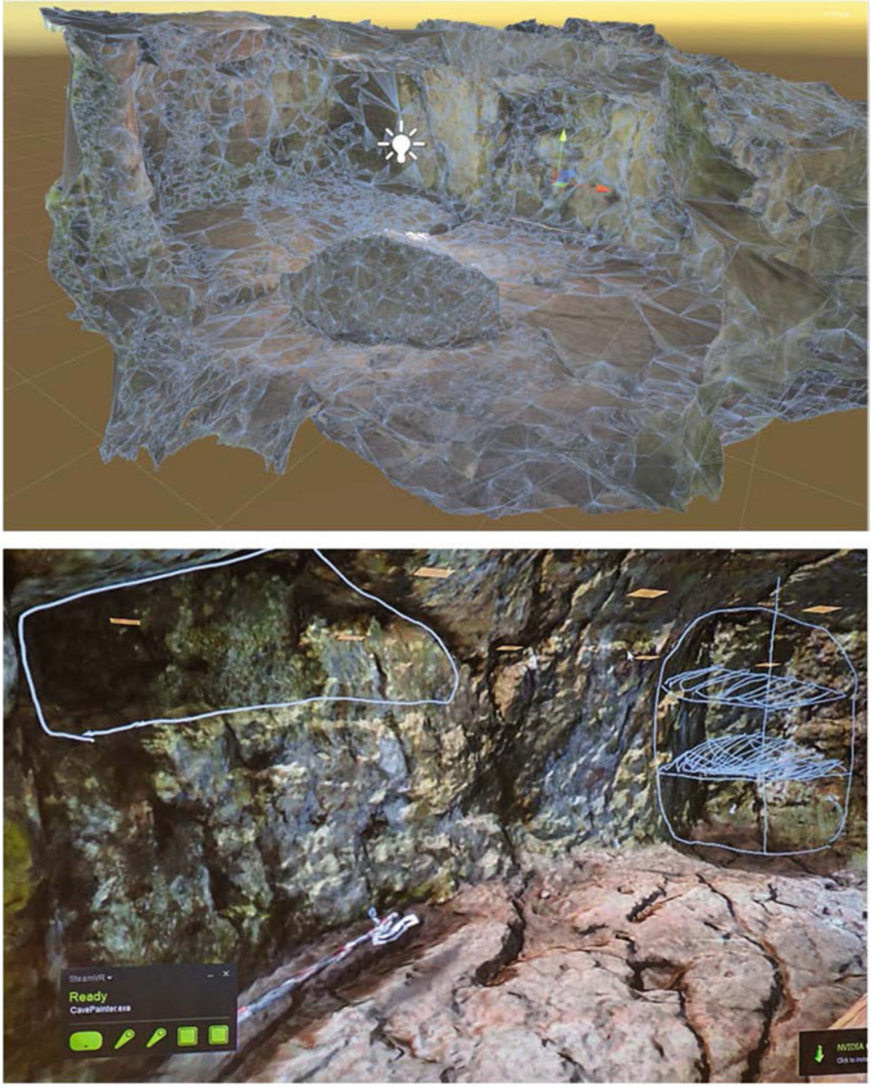

Fig. 3 Tests for importing a photogrammetric 3D model of a rock-cut room in unity for creating an immersive and interactive prototype

difficult. The documentation and study of these caves are also restricted by the poor lighting conditions that limits the visibility of carved features on the rock surface.

A rectangular room of about 12 m^2 was documented using photogrammetry, the photos were taken creating and oblique lighting in order to capture the micro-relief. The resulting model and the corresponding mesh were then scaled to the real dimensions and imported into Unity for further processing. The user was set to be inside the cave and could freely move within the space delimited by the model. The VR environment was built as a single user interface without possibility to switch to other visualisations. The focus of the prototype was the development of interactive tools, in particular a painting tool, suitable for marking specific features, map the surface of the room and visualise interpretative hypotheses. Using various brushes the user can directly annotate the rock-cut room, marking features, chronological elements and tool marks. The immersive model can be used as a notepad, observing, exploring and interpreting the tridimensional space as an open and transparent process.

For the cave prototype, we envisage a collaborative multi-user development, inviting researchers to draw their annotation in the virtual cave at the same time. All the tridimensional sketches should then be considered as single geometries and linked to controlled vocabularies, implementing a searchable database. Finally, the use of haptic gloves in such a context would enhance the potential of the interplay between the user and the material evidence. In fact, touch could be used to uncover discontinuities and asperities on the rock surface that would not be detectable through visual observation.

Developing both the Mesolithic dwelling prototype and the rock-cut cave, the use of Unity allowed for quick prototyping and a short iteration span between the conception and the test implementation in a virtual space. Unity relies on a large user community online, providing a handful of premade assets and comprehensive solutions that can speed up the frame development in order to focus more on project-specific features. Unity disposes of a large palette of tools and ways for creating a customised apparatus that encourages a participatory development. Researchers with different skills and background were invited to take part in the actual development, focusing on the process of building the VR prototype and fostering a reflexive approach to the digital craft. Inviting researchers to use the technology and participate in the development process helps perceive the potential of the application and recognise its limitations. Finally, the close collaboration of various experts helped define priorities and adjust to technical optimisations. In capturing dancing data, the multidisciplinary collaboration and direct involvement in the post-production processes helped toward the realisation of the prototype. Collaborative and iterative development, including several prototyping and testing phases, has shown to be the key for the progression of VR environments. In fact, this meticulous phase of apprenticeship is crucial for exploring potential and pitfalls hidden in the data. While ease of use makes it possible for non-developers to take part in the actual development, the collaborative prototyping helps reach a common understanding. Iteration and testing, as part of a reflexive approach, support an informed development of prototypes that rely on data availability and present new interactive tools.

4 Dynamic Cyberspace as Formative Resource

VR modelling has been designated as a potential ‘workshop of scientific research, an active and measurable space where to compare datasets, models, hypotheses, archives, and cyberspaces of interactive knowledge’ (Forte 2008, 97). In our experience, VR helped comparison and interaction amongst data supporting a transparent rendering of the interpretation process. This was the case of the Mesolithic site in Lillsjön, where the multiproxy dataset could be re-assembled without missing the archaeological spatial information and qualitative data from the dig. Discontinuity and gaps in the documentation (due to the limited excavated surface) were made visible through the import of GIS layers representing features and trampling levels. The spatial reference and position of findings established an important landmark for recreating the structure of the shelter through a participatory study.

Information generated through the programming and use of interactive tools reinforced the collaboration amongst researchers for the development of interpretative hypotheses. Sketching the lost apparatus of the rock-cut settlement was crucial for understanding an empty space and conceiving its biographic narrative. Itineraries of objects could be outlined in an immersive model acting as a digital canvas, while gaps in the information flow could be filled through a virtual depicted commentary.

Pedagogical aspects of the making emerged while combining different pieces of information in an attempt at rendering the complexity of the archaeological or historical record. The immersive simulation arena allows an interaction with the archaeological evidence that is not constrained by spatial or temporal hindrances. Users can browse an immersive fluid representation of space and time; visualise together data collected in different excavation campaigns and swiftly change position and point of view. VR can bolster the generation of new knowledge and the representation of archaeological data through ubiquity of time and space. Students participating in a Roman Pantomime performance were able to ask questions about place and people, as well as to reflect on the ephemerality of the senses and sound perception before electricity.

The pedagogical contribution of VR for understanding of ancient topography and the evolution of an urban space was tested using Google Earth for teaching ancient topography and the evolution of the centre of Rome to the students of the bachelor programme in archaeology at Umeå University. Google Earth supplies an interactive model for VR that reaches an acceptable level of 3D accuracy in the representation of buildings in urban centres. The urban fabric of a layered city such as Rome must be observed from different perspectives in order to acknowledge the complexity of scattered elements of the past persisting in modern buildings. Most of the time, undergraduate students do not have direct access to visiting historical city centres where the palimpsest of urban development is conspicuous. Thematic maps, in which the archaeological evidence is organised according to the chronology, represent the graphic support used for teaching and learning urban topography. While being very clear and useful for the comprehension of the ancient urban space, two-dimensional maps struggle to represent transformations and resilience.

Browsing a virtual photorealistic model of the city centre, students could cross a steady virtual space, move fast through different scales of observation and annotate significant benchmarks.

Two-dimensional maps representing some specific areas in a precise chronology were presented to the students (from Coarelli 2007) who were challenged to find and explore the corresponding space in the contemporary city, highlighting persistence and transformations. One student at time could act as a guide, wearing VR googles, being in control of the field of view and the proximity to the buildings. The goggles view was then projected on two big screens allowing the other students to respond as spectators/annotators, giving directions and pointing out relevant details. Users moved across two representations of the same space, overlapping the information coming from two separate sources (the map and the model) and creating links between the immersive environment and the 2D selected representation. During the exercise, students developed cooperative strategies to gain the best perspective on the monuments, unfolding details of the metamorphoses of the urban fabric.

An augmented immersive environment strengthens users' sense of presence, bypassing in some cases the lack of a complete sensorial engagement. The implementation of VR prototypes in archaeology classes could promote a broad understanding of the geographical context in which the sites are situated and stimulate student's enthusiasm and engagement. A first-person interaction with the digital model reinstates the slowness of the interpretation reconnecting the user to the craft of digitally rendered evidence and hypothesis. VR appears compelling in order to paraphrase archaeological practice and deliver it as a transparent pedagogical process.

5 Conclusions

VR prototype development supplies a powerful tool for interacting with the production of historical knowledge from an immersive viewpoint. The development of a new approach to historical information, allowing the rendering of mechanisms of knowledge production, seems the most compelling feature of VR applications. The interactive environments can be designed for the analysis of 3D features in a way that GIS cannot provide, through collaborative and iterative prototyping.

The collaboration with different research content in producing VR prototypes offered new insights. There is no comprehensive research about how such multidisciplinary collaborations may illuminate the value of technology as a tool for knowledge processes. Nevertheless, through the process of capturing and placing in a virtual environment the movements of Roman pantomime, we examined how the entanglements between technology, scholarship and performance art enable new knowledge production. Virtual reality in that sense acted as a lens that affects the way we conduct empirical and experimental research: it brings new conditions and demands for research.

The flexibility of game engines like Unity offers virtually no limits to the implementation of new tools to process and visualise information. Digital objects can render ideas, as in the case of the rock-cut settlement, where 3D annotations can frame lost objects and gestures. The sensorial engagement can confuse the users in their perception of space outside the VR environment, due to technological limits. VR allows the enhancement of some senses feedback, like vision and hearing, while, most of the time, disabling other ones such as touch and smell. The disproportionate sensorial experience of the cyber prototype supports a unique approach to the archaeological evidence. Tangible traces are partially deprived of their materiality in the digital representation while acquiring new properties that are embedded in features driving sensorial experiences.

The educational value of prototype-making is specifically expressed throughout collaborative practice. Cooperation amongst students was enhanced through experiential learning and sharing of information regarding the topography of Rome. Similarly, an instructive dialogue was generated through the virtual experimental workshop on reconstructing the wooden structure of the Mesolithic dwelling.

The development of VR prototypes represents an opportunity to explore technological agency within the disciplines of archaeology and ancient history. In all case studies, we have shown how VR applications can assist researchers in generating information both about the past and about the process of historical reconstruction itself. Immersive environments encourage a different approach to data processing and visualisation that must be mediated through an epistemological reflection over paradigms of knowledge production.

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