Virtual Reality Reconstruction Applications Standards for Maps, Artefacts, Archaeological Sites and Monuments

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Abstract Virtual Reality (abbreviated VR), although far from being a new concept in computer science, is increasingly considered nowadays as the digital media technology that can most directly linked with Archaeology and Archaeological Reconstruction (with the term "reconstruction" in this context being officially agreed on meaning the "re-building of a monument to its state at a time of its history chosen for that particular representation"). The potential along with the many degrees of freedom offered by this branch of technology in the sector recently led experts to even start talking about the dawn of the hyper-tourist era. The ever increasing amount of research in the area, as well as the number of actual archaeological sites that have been reconstructed in a VR environment to the present, appear to support both directly and indirectly such a strong statement. It is not an exaggeration to say that archaeological research is now dependent on VR more than ever before. Also, many of these applications include a pedagogical aspect in their design that makes them ideal educational platforms for students in archaeology and professionals in the area alike.

Introduction

Only a couple of decades back, at the beginning of the new millennium, VR was still considered to be a piece of technology that only future generations could hope to have at their disposal as a fully-fledged technological achievement. Although VR technology had by then already gone into its forth decade of development (officially VR history started with the release of the "Sensorama" VR device in 1962), the time when the average user would be able to interact with VR equipment on a daily basis at the convenience of his home was seemingly lying very far away in the future.

Now, almost two decades later, and VR equipment at least for some branches of the computer games development sector, is considered as standard equipment. The average user can buy at an affordable price not only a reliable VR headset and controllers, but even a VR Development Kit to start creating custom-made VRenabled applications (HTC Vive, Sony PlaystationVR, Oculus Rift & Samsung Gear VR). The available with VR equipment software (computer games and/or pedagogical software) has reached an availability considered before unimaginable and the prediction is that the global VR market concerning both developmental branches (hardware and software) will continue to grow exponentially for years to come **[1]**.

But what is VR? The truth is that there is no official definition of the term to include all aspects of this technological achievement. A generally accepted description (if not definition) for VR relevant to our discussion in this chapter could be: "every computer-generated environment of the kind that when a user is finding himself surrounded by feels like having transported into a new and fully interactive one, along with the involvement of created signals capable of deceiving the user's three of five senses (i.e. Sight, Hearing, and to some extent, Touch), when at the same time electronic devices respond to the user's input by accordingly adjusting the environment is surrounded by, is a VR environment".

In this respect and at a very early stage had become apparent that three types of applications were more than every other suited to VR technology. That is, Computer Games (including Serious Games), various types of Simulations and, Environment Reconstructions (including Architectural). Reconstruction of Maps, Artefacts, Archaeological Sites and Monuments, falls naturally into the last category (the first officially recorded use of VR in a heritage application was in 1994. The system was designed by engineer Colin Johnson and was featured in a conference held by the British Museum in November 1994. The first applications running on this system provided an interactive "walk-through" of a three-dimensional re-construction of Dudley Castle in England as it was in 1550 **[2]**).

Because reconstruction is very often confused with restoration and vice versa, needs to be made clear at this point that in the context of what we are about to discuss in this chapter, restoration is the procedure through which, starting with an original model and by means of manual interventions, we are trying to reinstate what has been destroyed, in an attempt to bring back the model to its original status. Reconstruction, on the other hand, is the procedure through which, when we are not in possession of an original model (because so little of it remains) we set to build it almost from the beginning, taking into account only some original remaining parts of it **[3]**.

Interdisciplinary Teams In VR Reconstruction Applications

As an old saying goes: "the whole is greater than the sum of its parts". In respect to the subject we are investigating in this chapter, we cannot but emphasise on how perfectly encapsulates the workings within an interdisciplinary team. That is, the very team structure that becomes the most key element when comes to recreating Maps, Artefacts, Archaeological Sites and Monuments in a 3D VR environment. Largely, this is because the very nature of the projects falling into the category we examine here calls for the involvement of a group of people who are trained on the use of diverse tools and among whom there is an organised division of labour around a common problem **[4, 5 & 6]**.

Mentioning here only the most key of the specialists involved in every recreational procedure of this nature, we need to naturally start from mentioning the Archaeologists; the very people that are expected to supply all the fundamental information. The Designers will take up the task of initially assembling this piece of information in such a way as to can be used from a computer science perspective. After that stage has been completed, the role of the Programmers in the team becomes important in the sense that these are the people who in the end will be entrusted with the translation of all the archaeological data and initial design work into a complete 3D model by using suitable computer games development software matched by some suitable VR hardware.

Building on each other's experience and work, each member of the team progresses the overall project from stage to stage so the final result achieved is as faithful as humanly possible to the archaeological data available.

As expected, such an approach comes with its challenges. Having several professionals, holding their expertise in different disciplines, gathered together and assigned a common task cannot by itself guaranty that everything is going to flow smoothly and they will necessarily function to the best of their abilities. It is not without reason that how to effectively work as part of an interdisciplinary team has become nowadays a major focus in the whole educational system.

User's Perception of a VR Environment

From the user's point of view, free movement in all directions; the ability to closely interact with surrounding objects and the overall environment in a highly realistic way; to wander the streets and enter a building; to take a closer look in order to come to appreciate artistic detail and the feeling that "you are actually there", are only a few key elements out of a list of attractions relating to VR technology. Users can now more than ever experience in full what an archaeological site was like, grasp more than the basics of its architecture, and get to appreciate how people used to live there as well.

A cracking combination of applications at an irresistible level of quality matched by fast hardware, make VR admittedly one of the most exciting branches of today's technology. VR applications really possess the ability to absorb a user's senses and irrespective of where looking, in a fully enabled 3D environment, to completely enclose him in an unbelievably realistic but imaginary world. That is, to achieve a transition from a completely real world to a completely virtual one. The transition from reality to the virtual domain is taking place through computational means, and the transition from the virtual to the reality domain is taking place through realism.

Of course, all the above are not to imply by any means that we do not have an even brighter future laying before us. State-ofthe-art VR hardware designed in the future, possibly including a fully integrated brain-computer interface system, will prove to be one of these crucial factors of improvement that will take the technology of this kind to the next stage.

A Virtual Reality Reconstruction Methodology

Of an outmost importance, in every field of science, is undeniably the methodology followed in order to obtain scientifically sound results. For projects in the field we are concerned with in this chapter, methodology is the procedure or set of procedures that outline the way in which stages unfold as part of the VR reconstruction process of Maps, Artefacts, Archaeological Sites and Monuments.

While in several other cases, as scientists working on a topic directly relevant to our field of expertise, we can use standard methodologies that have been tested for their validity under a number of different circumstances, archaeological VR reconstruction provides an additional challenge in the sense that being a rather new discipline lacks standards. This remains as true despite collective attempts to fill in the gap in recent years, since effectively archaeological virtual reality standards have not been revised since 2009/2012 **[5, 8]** or even since 2000 in many sectors **[9]**.

In this section we will attempt to outline a procedure with the potential to formulate a standardised VR reconstruction methodology and demonstrate the multi-disciplinary, open, interactive and transparent approach that such a methodology incorporates within its structure so can be considered suitable for the purpose **[10]**. The methodology unfolds in four stages that truly have suggested themselves while participating in development teams in the field as well as after reflecting on other peoples' experiences.

Typical Steps in a VR Reconstruction Process

Let us first concern ourselves with the predictable steps involved in a typical VR reconstruction project. This will enable us next to start sketching out the stages of a universal VR reconstruction methodology in the following sub-sections.

As already mentioned, the undeniable key element of every VR reconstruction project is a well-structured multidisciplinary team. The actual specialities in the team depend, in the general case, massively every time on the very nature of the topic investigated. In the specific context of the field that we are focusing on in this chapter someone could catalogue potential specialities needed as: archaeologists, anthropologists, hydrogeologists, architects, engineers, naval architecture specialists, programmers, designers and artists. Also, the addition of some external partners may prove necessary on the fly as the project unfolds, depending on individual challenges and difficulties arising either occasionally and/or on a calculated manner. In general, whatever the initial outline of the team involved, for every VR reconstruction project there are four fundamental layers requiring population by specialised people in the team, a) *realistic snapshot of the past,* b) *linking archaeological information and VR capabilities*, c) *analysis and design procedures* and, d) *archaeological/VR tools* (Fig. 1).

The case is that, as with every technical project, the fundamental commitment of a VR reconstruction project must be to quality. Quality, in this context, is reflected on the need to achieve in the end an as *realistic snapshot of the past* as it is possible at the time of reconstruction. This constitutes the foundation layer upon which the other layers in the scheme rest.

Directly supported upon the commitment to a realistic recreation of a snapshot of the past – namely, the next layer up – is the need for effectively *linking archaeological information and VR capabilities*. A major factor at this layer constitutes the realisation that not absolutely everything can be accommodated within a VR application, or, in equal terms, the realisation that not absolutely everything is convenient to be accommodated within a VR application. Admittedly, it is a fact that nowadays mentality has been shifted towards the consideration that today's computing machines come with unparalleled capabilities and an abundance of resources. While this turns out to be relatively true, still we are lying very far away from that point where we will be able as developers to create a virtual environment at the maximum humanly possible level of detail. Compromising with what we have available and making happen the absolute best that can be achieved by using existing resources has been the bread-and-butter of developers ever since the dawn of computing.

Before any application based on gathered data can be developed, the *analysis and design procedures* must have first been completed. In this third layer up, the emphasis is on achieving the best possible translation of the row data available so appropriate design procedures based on this translation can be enabled. By large the analysis and design procedures determine the overall success of the task at hand.

The possibility of one's goal achieved by inappropriate, or even half-appropriate, tools is admittedly minute in the VR reconstruction world. An ideal combination of both automated and semi-automated *archaeological/VR tools* will in principle lead to practising a safe and error-proof procedure in gathering and prototyping data, respectively.

So, by considering what discussed so far, and taking a topdown approach, we can summarise by saying that the first challenge a VR reconstruction project team is to be faced with is the selection of the appropriate tools.

Stage 1: Selecting an Archaeological Site and Tools for Collecting Archaeological Data
Has been acknowledged since the early days that a good practise to follow in choosing an archaeological site for reconstruction is to consider, at a first filtering stage, those available that come (from a scientific point of view) from a well-known historical period. At a second filtering stage, to consider those offering best chances for a good VR reconstruction that will be based on a very specific moment in history. A sequence of events can then added around the main reconstruction, for which we may possess only partial knowledge. The actual requirement here is for the user to be informed of the fact that these additional events are including archaeological recreation based not on solid facts throughout but, rather, on previously scattered historical information later reassembled and interpolated.

Archaeologists are primarily based for their judgement of the past on excavation reports, historical research, iconography and/or historical landscaping. Also, nowadays, ever more increasingly, they are based on geophysical scanning as well. Assisting to these techniques are secondary ones like: hydrography, anthropology and physical reconstruction. Not all of them can offer reliable information in all cases, and for this reason a very objective assessment of the information provided by each is first required.

The next step constitutes the correlation phase, which focuses on comparing information. That is, during correlation, the archaeologist attempts to identify what collected and documented information can be considered as reliable, what possible further processing of the information is required, what can be expected from the information, what constraints exist in relation to the information, and what validation criteria are required in order to come to sound conclusions based on those pieces of information that have been labelled as reliable.

It is also a common practice, at this stage, for the team to require the construction of the so called "preliminary comparative/experimental models". Usually, such kind of models are not based entirely on archaeologically proven facts and their only purpose is to provide a first idea (like a first draft) of what line the VR reconstruction is to follow later. Despite of what effort put into the construction of such models no one in the team is expected to rely on them for drawing final conclusions. In the best of cases, such models will be subjected to many revisions, if not at some point discarded all together.

The undeniable tool(s) of the last twenty years in archaeological VR reconstruction is the latest generation of archaeological geophysical survey methods. Among them two are the most widely used and praised for the quality of the results produced. These are the Ground-Penetrating Radar (GPR) method and the Electrical Resistivity Tomography (ERT) method. Very often in practice GPR and ERT (Fig. 2) are the only geophysical methods considered, primarily because of their fundamentally non-invasive nature as methods and secondarily because of the directly transferable to a 3D mapping results they offer.

Of course none of the two techniques is to be taken as the absolute optimum for the purpose; since they are both prone to errors and cases where they have failed to yield useful results have been reported. As field archaeologists very well know, many lessons about applying geophysical survey methods have come to be learned from sporadic success and failure, as well as from the realisation that conditions at some archaeological sites may not permit for the application of geophysical survey methods at all.

Much more recently, two additional methods have been added to those mentioned above with very promising results; these are the Digital Camera Imagery (DCI) and the Laser Scanning (LS) methods. In particular, the Laser Scanning method is an immensely convenient one when it comes to VR reconstruction because of its ability to directly capture 3D images of an archaeological site that can almost immediately fed into a 3D imagery processing tool. Very often, especially in artefact reconstruction related projects, the Laser Scanning method is paired with 3D printing.

From our discussion about archaeological and technical field methods, must have become apparent that the archaeological site selection and the geomorphological identification of the structure of the site, are two phases in the overall methodology the significance of which is hard to overestimate. The end goal here is primarily to locate an archaeological site within its geographical/geophysical context. With this achieved, the VR reconstruction will in succession succeed in localising the archaeological site at a realistic terrain assisting enormously that way in users' perception of the reality of the historical period the particular reconstruction falls within.

Usually considered of secondary importance, but nevertheless deserving attention at the initial stages of every VR reconstruction related project, is the issue of considering what kind of vegetation would have possibly existed at the time. Realistically, reconstructing the terrain of an archaeological site is one thing, but being able to populate this very terrain with the appropriate grass, bushes, plants and trees, is completely another.

As an extension to the above requirement also comes the necessity for accounting for the human-made transformation to the vegetation layer arising from the creation of access routes, agricultural exploitation and extraction of mineral resources related activities. No civilisation has ever been in existence that carried out its activities in a totally environmental friendly way. All civilisations, one way or another, caused a documentable effect on the environment inhabited. For some particular archaeological sites an accurate, to the extent that this is feasible, reproduction of the effect of human activities on the environment may be of substantial importance in projecting a fully-fledged picture of the period reconstructed to the user.

Stage 2: Reconstructing the Archaeological Site

As soon as the archaeological data have been assembled; then assessed and validated from a scientific point of view, the categorisation of them thematically leads to a first-impression creation of the archaeological site itself.

Usually, the reconstruction is firstly based on recreating the peripheral to the main structures, along with the creation of models and textures. The civil infrastructure can follow, by considering streets, walls, trenches, pathways, bridges, etc. to assist primarily in creating the 2D outline of main buildings and other constructions, so can later the 3D volumes of them can be determined.

At a final stage, the creation of all the movable elements of the reconstruction can be considered. Furniture, and various other artefacts, can be based on actual excavated items or items prototyped after textual descriptions.

At the purely technical sector, 3D models of land and buildings can be constructed from 3D maps, leading to the creation of geometrical meshes that then can be used to represent the objects within a game engine. Also, 3D outlines and vectorised drawings exported to a 3D format have been very successfully used in the past for reconstructing landscapes and architectural features.

The point at which we need to pay particular attention at is in relation to the methodology followed for constructing the virtual models. Many practitioners in the area agree, and personal experience has verified, that the best policy is for someone to continuously check the models for scientific accuracy. This means that thorough checks need to be carried out even at primitive stages when the models only exist as meshes and extended throughout the entire process. By following this simple methodology can be made sure that when the need arises to introduce any essential corrections to the models these corrections will have an effect only on the points of interest, and not on the entire model or even on the textures created much later. Needless to say, this will eventually lead to a highly recursive procedure that will have to be faithfully repeated for every single model in our VR reconstruction.

Stage 3: Tools for Reconstructing Archaeological Sites, Maps, Artefacts, and Monuments
Software packages like “Cinema4D”, “Blender”, “Maya” and “3D Studio Max” can be used for recreating landscapes and architectural features alike, while both “Unity3D” and “Unreal Engine 4” game engines have to offer an integrated, straight forward to use, and very powerful landscape creation component.

When all models (i.e. for the terrain, the vegetation, the pathways, the lakes and/or rivers, the buildings and the artefacts) are ready, they can be imported into a game engine for the final assembly of them to provide a photorealistic quality overview on how the overall creation looks like. Easy and straight forward assembly of models in a fully enabled 3D environment and photorealistic quality, though, are not the only attractions for using a game engine for the purpose. All modern game engines meeting professional standards like “Unity3D” and “Unreal Engine 4” can directly export projects for application on a variety of platforms, including all VR platforms (i.e. Multiscreen Projection, Virtual Reality Headsets, etc.)

The traditional (and still recommended by many practitioners in the field) way of navigating through the VR reconstructed world is by means of using the VR Headset and the Touch Controllers. The by default set functionality of these two devices is for the headset to translate user’s head movement into a change in the field of vision (the measurement per unit is in degrees) and for the touch controllers to translate user’s hands movement into a corresponding virtual hands movement (the measurement per unit is in pixels). These two main functionalities are complemented by a secondary one found on the touch controllers and provided by means of an analogue stick (full 360^o degrees spinning capability around the central vertical axis) that can be used for “walking” around in an area (the measurement per units is in degrees and pixels).

Although this standard functionality will offer all a developer needs in most of the cases and is the optimum solution for third-person scenarios, had from a very early stage become apparent to the author that by sticking to this functionality someone limits the sense of realism in first-person applications like VR reconstruction applications fundamentally are.

Simply stated, in our everyday lives we perceive our environment in first-person and we are not using an analogue stick to walk ourselves around the environment we inhabit. Thinking about possibilities in improving on this, the author devised an alternative navigational method as part of a VR reconstruction project undertaken at the University of Northampton, UK in collaboration with the Caroline Chisholm School, Northampton, UK (the project was funded by a partnership grant from The Royal Society, partnership grants summer 2017, PG\170067).

The core software for the project was written around the VRTK Virtual Reality Toolkit **[11]**, an extension software package written for the “Unity3D” game engine. For the implementation, the standardised primary role of the navigation devices, VR Headset and Touch Controllers, was maintained, with a variation introduced at the way the walk-through functionality was achieved. Instead of using the analogue stick for the purpose, the A-button on the righthand touch controller was given a Boolean functionality. When released (equivalent to state “false”), the control devices function under their primary functionality (Standard Mode of operation) with no walk-through. When pressed (equivalent to state “true”), head movement is combined with walk-though functionality (Walkthrough Mode of operation). In this second case, the user experiences a situation where head movement changes the visual field while at the same time experiences walking towards the direction indicated by the visual field line of sight. Walk-through Mode of operation is achieved by a series of decisions hard-wired in the code and implemented on the basis of the human visual field pattern (Fig. 3).

In this context, when the user’s head is detected to be in the area of the right-hand-side or the left-hand-side monocular visual field, the user experiences a full 90^o turn in respect to the vertical meridian of the visual field towards the corresponding direction, along with walking movement towards the far point indicated by the direct horizontal line of sight. When the user’s head is kept within the area of the central 20^o of the visual field, the user experiences a straight ahead type of walk-through movement towards the far point indicated by the direct horizontal line of sight with an at the same time 0^o turn in respect to the vertical meridian of the visual field. Finally, the user’s head found within the area of either one of the binocular visual fields results to as many degrees turn towards the corresponding direction.

As an extension to this the author is now working on developing a navigational system that will include along with the standard VR equipment an eye-tracking device and a Brain-Computer Interface (BCI) device. With positive results already achieved, when the system is ready, the hope is, to be able to introduce another degree of freedom in the hyper-realistic experience offered to the user when engaging with a VR application. That is, the feeling of an absolute transition for the user to the virtually reconstructed world casually achievable and independent of application characteristics **[12]**.

Stage 4: Data Acquisition or "The Battle for Realism" in VR Reconstruction Applications

By attempting someone to discuss the problem of realism standards in VR reconstruction applications, namely, how realism can be achieved, what are its limitations, etc. needs necessarily to also discuss, in direct relation to this, the problem of obtaining those detailed data necessary for achieving the highly realistic reconstruction. This problem, throughout the years since the introduction of data-based science, has acquired the special name "The Data Acquisition Problem".

The significance of this problem becomes apparent when we come to understand that the representational quality of every model recreated is mirroring the quality of the original detailed data obtained in relation to that model.

With all the above mentioned, the importance of real data to base on the representation of every model taking part in the reconstruction, cannot be overestimated. In general, many practitioners in the field suggest that three fundamental steps need to be taken when an as accurate as possible representation of objects in a digital reconstruction is required. These are:

1. To make every effort possible to obtain realistic high-quality images.
2. To post-process these realistic images for maximum quality.
3. To superimpose all obtained information (as discussed in the previous section) on the real images to maintain close contact with reality for those models requiring the intervention of human creativity to fill in possible gaps.

Throughout the previous decade obtaining realistic images of objects' appearance and converting them into useful row data was a process that was requiring manual handling, the employment of stereo-photogrammetry surveying, 3D laser-scanners, or any combination of the three. Particularly the laser-scanner technique, since its first introduction in the field, with its ability to provide the spatial coordination of the surface points of the objects of interest had been proved a really invaluable tool. Nevertheless, as invaluable as it might have been proved, there is a well-known drawback associated with the technique. Using a laser-scanner in a massive scale (and ignoring at this point the relatively high cost involved), automatically means the generation of a huge amount of data, the distribution of which over the web or their use in web-based applications is problematic; particularly when there is a need to deal with large objects possessing many parts that require to be detailed.

Nowadays, a new technique has come to substitute for this practice that takes advantage of the capabilities and the many degrees of freedom offered by the Small Unmanned Aircrafts (SUA) (those flying devices we are accustomed of collectively calling "Drones"). Although drones have been identified as particularly suitable in bridging ground-based surveys and expensive air-borne remote sensing, can also handle situations where general landscape and individual buildings or other structures have to be investigated stretching the spectrum of potential applications from landscapes, to excavations, to monuments, to buildings and many more.

In reality, the application of a drone-based technique combines the best of many worlds with its capability to offer higher resolution 3D data (processed by a photogrammetric software application), in a shorter period of time and at a significantly lower cost than the majority of the other well-known techniques including Airborne Laser Scanners (LiDARs – Light Detection And Ranging) when applied using a full size aircraft.

Relatively recently (2016), has been reported **[13]** that a combination of a drone and laser-scanner (Drone-mounted Laserscanner) achieved excellent results at a site of interest that was initially considered of presenting unsurpassed difficulties. The difficulty factor was mainly due to the site being completely covered by trees. By using very effectively the main characteristic of this new technique, which comes as a result of a combination of extremely rapid in succession and very dense laser pulses used, the involved technicians managed to get enough laser beams to reach through to the ground that made for enough points of reference. While, at the same time, many millions more of laser beams were bounced off the leaf canopy. In the end all the reference points gathered were used to create a model of the surface, which could then be further examined and processed.

Despite the level of modernisation data acquisition techniques are currently experiencing, the goal of any modelling process remains fundamentally the same. That is, to create a high resolution, as accurate as possible, representation of the site of interest. The answer to this problem is to proceed in an uneven manner, starting from the creation of a large scale unrectified model including a superposition of all the acquired data, before specific details for which even more data will be needed are introduced. It is at this very stage that acquired data that initially had produced components of the model that seemed valid when treated individually may prove as producing a completely different visual result when viewed in the context of the big picture.

The whole of the data acquisition problem can be viewed collectively, as have been treated in our discussion so far, or even as individual entities that can be summarised as below:

- The data required for the 3D geometry models.
- The data required for the photorealistic rendering of models' surfaces (i.e. light, textures, etc.).
- The data required for allowing the creation of interactive surfaces for the user to interact with.
- The data required for allowing for realistic movement in the VR environment.
- The data required for accurate reproduction of both models and VR environment in the case of other display means than a simple computer screen.

The final aspect in our discussion about the data acquisition problem is that of Data Integration. From what discussed above must have become apparent that in extremely rare situations only we will be faced with the relatively straight forward problem of having to deal with data that have been gathered using only one data acquisition method. In the grand majority of cases we will need to integrate data that have been acquired using a variety of methods.

The solution exercised for a good number of years now to address this problem requires the gradual addition of data, as acquired, directly into a Data Integrated Environment that is implemented and maintained as a single platform. The most characteristic example of such an approach is the Integrated Archaeological Database System (IADB) developed and used by the Scottish Urban Archaeological Trust (SUAT) **[14]**. Since then, any major or minor database system build for the purpose comprises in one or the other way the following elements making up the prototype structure of this original database:

- *Section 1*: Data related to the creation of the VRenvironment.
- *Section 2*: Data related to the creation of the models (wireframes).
- *Section 3*: Data related to the application of textures on the VR environment.
- *Section 4*: Data related to the application of textures on the models.
- *Section 5*: Data related to the various relationships between the environment and the models.
- *Section 6*: Data related to specific links between environment and models.
- *Section 7*: Data related to photorealistic digital images (textures) used for creation of duplicates or variations in case of procedurally generated extensions to the original design of the VR environment.

Retrieving of the data takes place by means of using a Structured Query Language (SQL) to query the database. Then the results of those queries can be further processed before used for rendering the actual VR environment and the models.

Because of this need for further processing the preference here is to store data leading to baked textures in order to avoid employing the multi-pass rendering technique. Despite the fact that this practice may lead to a requirement for higher storage capacity, still is considered much more preferable because of the ability to combine material decals with illumination texturing.

Conclusion

This chapter is the result of an attempt to create a basis for the formulation of a precise recreational and data acquisition methodology for VR reconstruction projects, emphasising on good practises that have been tested in a number of related to the field projects.

Particular emphasis paid on the degrees of freedom offered by today's technology in relation to archaeological site investigation, data gathering, data analysis and reconstruction. The distinction was also made between VR reconstruction for visualisation purposes and VR reconstruction for conducting research purposes.

Applications in the area of VR reconstruction have now opened up possibilities for standardisation in both reconstruction practises and applications' quality since the advantages offered by virtual models have become more than evident. Current research in the area of integrating Brain-Computer Interface and Eye-Tracking technology with the standard VR input devices and controllers suggests that in near future the applications spectrum for VR will become even more broad, with user experience reaching unparalleled levels of realism.

Of course, in relation to the above mentioned, we will need to fully appreciate at some point the fact that such a developmental route will potentially demand the involvement of scientists from other branches than the usual, and especially that of psychologists and sociologists, to mention just the two most obvious, in order to assess the potential psychosocial impact of VR reconstruction applications.

References

1. "Virtual Reality (VR) Market Analysis By Device, By Technology, By Component, By Application, By Region, And Segment Forecasts, 2018 – 2025", https://www.grandviewresearch.com/industry-analysis/virtual-reality-vr-market, Report ID: GVR-1-68038-831-2, May 2017.
2. Tony Higgins, Peter Main, Janet Lang, British Museum (eds.), "Imaging the Past: Electronic Imaging and Computer Graphics in Museums and Archaeology", Volume 114 of British Museum London: Occasional paper Issue 114 of Occasional paper, British Museum, ISSN: 0142-4815, ISBN: 0861591143 9780861591145, 1996.
3. "Virtual Reality And Archaeological Reconstruction: Be There, Back Then", MW17: MW 2017, Published February 2017, Consulted May 2019. https://mw17.mwconf.org/paper/virtual-reality-and-archaeological-reconstruction-be-there-be-back-then-ullastret3d-and-vr-experience-in-htc-vive-and-immersive-room/
4. Susan Nancarrow, Andrew Booth, Steven Ariss, Tony Smith, Pamela Enderby & Alison Roots, "Ten Principles of Good Interdisciplinary Team Work", Human Resources for Health, 11.10.1186/1478-4491-11-19, 2013.
5. Beacham, Denard & Niccolucci, "The London Charter – For The Computer-based visualisation of Cultural Heritage", The E-volution of ICTechnology In Cultural Heritage, Papers from the Joint Event CIPA/VAST/EG/EuroMed Event, 2006, [http://www.londoncharter.org].
6. Vassilios V., John K., Manolis T., Michael G., Luis A., Didier S., Tim G., Ioannis T. C., Renzo C. & Nikos I., "Archeoguide: First Results of An Augmented Reality, Mobile Computing System In Cultural Heritage Sites", proceedings of the 2001 conference on virtual reality, archaeology and cultural heritage, Glyfada, Greece: ACM, 2001.
7. Vlahakis V., Ioannidis M., Karigiannis J., Tsotros M., Gounaris M., Stricker D., Gleue T., Daehne P. & Almeida L., "Archeoguide: An AR Guide For Archaeological Sites", computer graphics and applications, IEEE, Vol. 22, pp. 52-60, 2002.
8. Hugh Denard, "A New Introduction To The London Charter", (eds.) A. Bentkowska-Kafel, D. Baker & H. Denard, Paradata And Transparency In Virtual Heritage Digital Research In The Arts And Humanities Series, Ashgate, 2012, [http://www.londoncharter.org].
9. D. Pletinckx, D. Callebaut, A. E. Killebrew & N. A. Silberman, "Virtual-reality Heritage Presentation At Ename", IEEE MultiMedia, DOI: 10.1109/93.848427, Vol. 7, No. 2, pp. 4548, April-June 2000.
10. Juan Barcelo, "Visualizing What Might Be. An Introduction to Virtual Reality in Archaeology", Virtual Reality In Archaeology, Archeo Press, J. A. Barcelo, M. Forte, D. Sanders (eds.), pp.9-36, 2000.
11. https://vrtoolkit.readme.io.
12. Murtada Dohan & Mu Mu, "Understanding User Attention In VR Using Gaze Controlled Games", TVX '19 Proceedings of The 2019 ACM International Conference on Interactive Experiences For TV And Online Video, p.p.167-173, June 05-07 Salford (Manchester), UK, ISBN: 978-1-4503-6017-3, DOI:10.1145/3317697.3325118, 2019.
13. https://www.mola.org.uk/blog/drone-mounted-lasers-see-between-leaves.
14. Rains M. J., "Towards a computerised desktop: the Integrated Archaeological Database System", In J. Huggett and N. Ryan (eds.), pp. 207–10, 1995.
15. Yoana Slavova & Mu Mu, "A Comparative Study of The Learning Outcomes And Experience of VR In Education", IEEE Conference on Virtual Reality and 3D User Interfaces (VR) – Conference Paper, DOI: 10.1109/VR.2018.8446486, 2018.
16. M. Pollefeys, M. Proesmans, R. Koch, M. Vergauwen & L. Van Gool, "Acquisition of Detailed Models For Virtual Reality", Virtual Reality In Archaeology, Vol. 843, BAR International Series, CAA, Archaeopress, Publishers of British Archaeological Reports, pp. 71-77, 1998.
17. Giovanni Saggio & Davide Borra, "Augmented Reality For Restoration/Reconstruction of Artefacts With Artistic or Historical Value", DOI: 10.5772/27066, In Book: Augmented Reality Some Emerging

Application Areas, 2011.
18. G. Papaioannou, A. Gaitatzes & D. Christopoulos, “Enhancing Virtual Reality Walkthroughs of Archaeological Sites”, 4th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage, The Eurographics Association, 2003.
19. Georgia Kyriakaki et. al., “4D Reconstruction of Tangible Cultural Heritage Objects From Web-retrieved Images”, International Journal of Heritage in the Digital Era 3.2 (2014): 431451.
20. Marinos Ioannides et. al., “Online 4D Reconstruction Using Multi-images Available Under Open Access”, ISPRS Annals of the Photogrammetry, Remote Sensing and Saptial Information Sciences, II-5 W 1 (2013): 169-174.
21. Anastasios Doulamis et. al., “5D Modelling: An Efficient Approach For Creating Spatiotemporal Predictive 3D Maps of Large-scale Cultural Resources", ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences 2 (2015).
22. Konečný, R., Sylaiou, S., Liarokapis, F., “Procedural Modeling in Archaeology Approximating Ionic Style Columns for Games”, Proc. of the 8th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games 2016), IEEE Computer Society, Barcelona, Spain, 7-9 Sept, 1-8, 2016.
23. Noghani, J., Anderson, E., Liarokapis, F., “Towards a Vitruvian Shape Grammar for Procedurally Generating Classical Roman Architecture”, Proc. of the 13th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST 2012, Short and Project Papers, Eurographics, Brighton, UK, 19-21 November, 41-44, 2012.
24. Noghani, J., Liarokapis, F., Anderson, E., “Procedural Generation of Urban Environments Through Space and Time”, Proc. of the 31st Annual Conference of the European Association for Computer Graphics (Eurographics 2010), Poster Session, Norrkoping, Sweden, 4-7 May, 2010.
25. White, M., Mourkoussis, N., Darcy, J., Petridis, P., Liarokapis, F., Lister, P.F., Walczak, K., Wojciechowski, R., Cellary, W., Chmielewski, J., Stawniak, M., Wiza, W., Patel, M., Stevenson, J., Manley, J., Giorgini, F., Sayd, P., Gaspard, F., “ARCO-An Architecture For Digitization, Management and Presentation of Virtual Exhibitions”, Proc. of the 22nd International Conference on Computer Graphics (CGI'2004), IEEE Computer Society, Hersonissos, Crete, June 16-19, 622-625, 2004.

Fig. 1: The four fundamental layers involved in every VR reconstruction project.

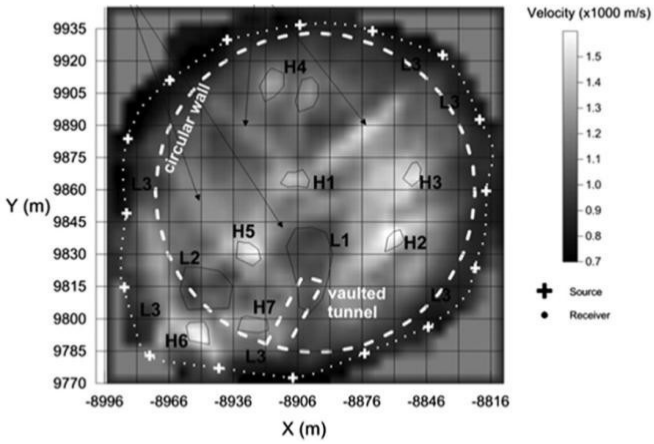

Fig. 2: Plan view map of Electrical Resistivity Tomography (ERT) survey results from the Amphipolis Tomb in Macedonia, Greece.

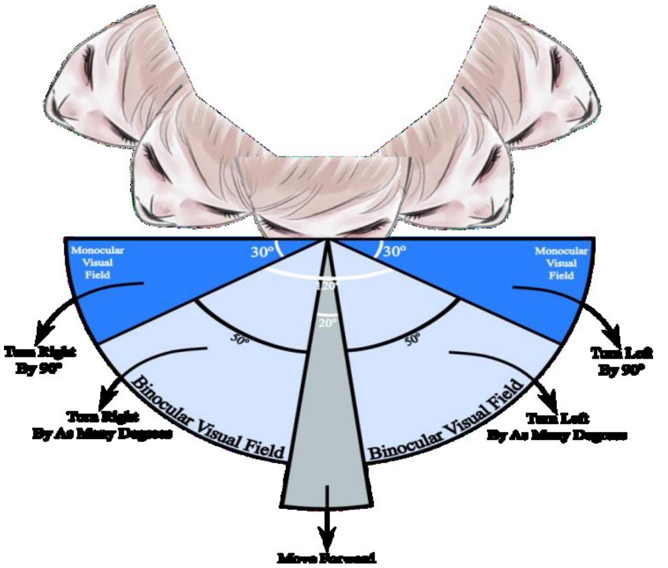

Fig. 3: The Human Visual Field pattern. With the A-button on the right-hand touch controller pressed (equivalent to Boolean state "true"), head movement is combined with walkthough functionality (Walk-through Mode of operation).