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Original article

Experiential archaeology: Is virtual time travel possible?

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Abstract

Advances in computing hardware coupled with its software counterparts have, for the past decades, influenced to a greater extent both the workflow of archaeologists and their interpretation of archaeological data. On the leisurely periphery, the synergy that arises between entertainment demands and commercial driven developments of interactive 3D (i3D) computer games has pushed these technologies beyond the expectations of the Virtual Reality (VR) community. This phenomenal growth in useable technology and its proportionate decrease in price have benefited the applicability of VR which in turn, have made it more accessible for researchers wishing to harness its benefits. The last 10 years have seen a steady increase in the use of VR technology to restore, preserve, reconstruct, recreate, and visualise ancient sites, monuments and artefacts. But, is technology ready for virtual time travel (VTT)? This article examines the possibility of experiential archaeology in voltage and silicon with the aim of formulating a strategy for VTT.
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Keywords: Virtual Time Travel; Experiential Archaeology; Virtual Reality; Mixed Reality; Artificial Life; Artificial Intelligence; Presence

1. Introduction

Experiential archaeology describes an attempt to access the past human existence, via synthesis of their experience by various practical means such as being in the wild, spending days without shelter, feeling the adrenaline of hunting, anticipating a meal while butchering, feeling the warmth by the fire, etc. As opposed to experimental archaeology [1,2], which offers insights into material facts in the past via the practical creation of historical artefacts using only historically available technologies, experiential archaeology brings participants into the experience of living as an ancient inhabitant. The former posits the importance of material facts, while the latter on the human experience of being within the material facts. The integration of the processual and experiential approach in the study of prehistoric sites and landscapes is an important factor in archaeological interpretation. It is noted [3,4] that whilst a scientific approach, incorporating geological and ecological variables, is indispensable, it has become recognised that the subtleties of embodied space, essentially the experience of "being in the world", is important in the interpretation of the spatial relationships between monuments, spaces between monuments and the routes that connect them [5]. Interpretive archaeology, a recent trend in archaeology is important and Monod and Klein [6] have provided four fundamental concepts of interpretive archaeology – re-enactment, embodiment, hermeneutics and phenomenology.

The New Technologies for Cultural and Scientific Heritage of the European Commission's report [7] states that "Computing hardware and software have advanced to a point where it is possible to construct and view models using personal computers. Further technological improvements will soon enable these models to be immersive, interactive and involving. Developments in the speed of networks make it feasible to deliver these models over the Internet." (p. 18). The report in 2002 [8] states that Virtual Reality (VR) and Mobile Technology are expected to provide "an impressive, immersive, interactive and involving product" (p. 91), and to give a "sense of personal presence of the user in its environment" (p. 114).

Experiential archaeology in Virtual Time Travel (VTT) attempts to synthesise real-world phenomenon by digitally recreating sites, monuments, and artefacts (subject to the accuracy and availability of data) within an interactive Virtual Environment (VE). The main objective is to create an experience

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of "being there" so that users could experience what it was like to live in the past. The motive is to bring a distant world into a psychological reality. But how can we create a sense of "being there" [9]? This article explores the attempts of researchers in multidisciplinary fields, reviewing the present state of technology and its suitability for virtual experiential archaeology.

Section 2 sets the scene and a conceptual background for VTT, reviewing past attempts at psychological immersion with media and within mediated environments. Section 3 examines the state of technology to see if experiential archaeology in voltage and silicon is presently possible. Section 4 presents case studies that investigate past attempts of VTT in archaeology. Finally, section 5 concludes with a discussion of the article and future trends.

2. Methodologies for VTT

Literatures in the field of Computer Graphics (CG), VR, and psychology have shown that the sense of believability can be induced via various means. Presence is defined by Lee [10] as "a psychological state in which virtual objects are experienced as actual objects in either sensory or nonsensory ways". Steuer [11] stated that presence is the extent to which one feels present in the mediated environment rather than in the immediate physical environment. Slater and Wilbur [12] defined it as a "state of consciousness, the (psychological) sense of being in the VE". A thorough review of literature related to the presence phenomenon by Lombard and Ditton identified six different conceptualisations of presence: presence as social richness, presence as realism, presence as transport, presence as immersion, presence as social actor within medium, and presence as medium as social actor. Comparing the commonalities between these conceptualisations, Lombard and Ditton provided a unifying definition of presence as the "perceptual illusion of non-mediation", that is, the extent to which a person fails to perceive or acknowledge the existence of a medium in his/her communication environment and responds as he/she would if the medium were not there. This can be associated with the disappearance of the technological interface, one of the main goals of Human-Computer Interface (HCI) research [13].

Ijsselsteijn and Riva [14] noted that presence seems to be one of the basic motivations behind the appeal of media in general, and the fascination with VE. They proposed two general categories of variables in a general framework of presence that are likely to play a role in determining the presence experience – media characteristics (media form and media content) and user characteristics. Both are needed to induce presence. Research have shown that reading novels or written narratives could "transport" a reader into the story [15], this effect is called psychological immersion, which brought the reader into another world. Watching television could also induce psychological immersion. Kim and Biocca's study [16,17] on subjects watching television reported on the following perceptions: "When the broadcast ended, I felt like I came back to the 'real world' after a journey", "The television came to me and created a new world for me, and the world suddenly disappeared when the broadcast ended", "During the broadcast, I felt that I was in the world the television created", "the television-generated world seemed to me to be more like "somewhere that I visited" rather than "something that I saw" and "my body was in this room, but my mind was inside the world created by the television". Kim and Biocca's self-reported measure of presence yields two factors:

- arrival, for the feeling of being there in the VE;
- departure, for the feeling of not being there in the physical environment.

If written narratives can provide psychological immersion, and watching television yields the feeling of arrival and departure, adding interactivity to a mediated world should further enhance immersion. It is generally believed that the greater the number of human senses is involved, the more presence a participant experiences. Lombard and Ditton [18] stated that in general, our visual and aural senses dominate our perception and have been most often identified with presence. Short et al's study reported that subjects felt greater social presence after an audio-visual task-based interaction than an audio-only version [19]. This shows that task and activity-based interactive virtual worlds can generate the sense of presence.

Sheridan [20] stated that the difficulty of the task and the degree to which the control of the task is manual versus automatic may each influence presence, although very little is known about the influence of any of these task/activity variables [18]. Observations of players of first-person shooter using Fishtank VR (standard display monitor [21,22]) often encounter the "corner phenomenon" – when a player tries to look over the corner of a wall to see whether there are enemies at the other side of the wall or the doorway, their physical bodies lean in relation to the movement of their avatar (virtual representation). Users of 3D environments also experience the "falling effect" where the stomach churns when they virtually jump or fall off from high places. In this case, sudden vertical movement seems to affect the physiology of the user. Such experiences of immersion in game play seem to suggest that presence occurs when users are engrossed in a task, in this context, interactivity in a VE. While playing with Artificial Intelligence (AI) gave a sense of presence, a recent study [23] showed that playing with human-controlled opponents seemed to increase the experience of presence even more. Heeter [24] suggests that "people want connection more than any other experience. Placing more than one person in a virtual world may be an easy way to induce a sense of presence regardless of the other perceptual features of the world". The ability to interact with large number of groups as in a multi-user VE may lead to even greater presence [11,25]. These multi-user environments include Massively Multiplayer Online Games (MMOG), Massively Multiplayer Online Role Playing Games (MMORPG), and Multi-user virtual worlds such as Second Life [26]. In fact, the experience within the Multi-user virtual world is so real that users often dated [27] and married either in the real life [28], or in their Second Life [29]. A field of study suggests that the boundary between virtual worlds and reality may be more porous than experts previously imagined [30]. In a study [27], respondents were asked to compare the quality of their MMORPG friendships with their real-life friendships. Around

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39.4% of male players (2971) and 53.3% of female players (420) felt that their MMORPG friends were comparable or better than their real-life friends. The same study also showed that 5.1% of male players (2991) and 15.7% (420) of female players had physically dated someone whom they first met in an MMORPG.

Why presence occurs? Lee proposes that human beings can feel presence due to the automatic application of two types of causal reasoning modules – folk-physics modules for knowing about physical causation, and folk-psychology modules for knowing about social causation when they respond to mediated and/or simulated objects [31]. Actual analysis and experimentations by Luciani et al. [32] suggests that connecting the high level visual realism possible today to the action channel is not sufficient to elicit a robust feeling of presence, so does auditory feedback, even though it enhances more often a deeper sense of reality. Luciani et al. suggest that an "evoked matter" – the existence of matter responsible for the dynamic correlation between real sensory-motor events induces the presence phenomena. The suggestions of these research shows that for VTT to be possible, some underlying mediums must be present:

- high-level visual realism;
- aural channels (ambience and feedback);
- narrative and task-based environment;
- interactivity (contents: agents and objects);
- artificial intelligent agents and artificial entities or presence of human-controlled avatars;
- non-intrusive interfaces (Hardware, software).

The virtual world can further be enhanced by the addition of other sensory inputs such as touch, smell, and feel (wind, cold, heat).

For the sake of laying a foundation addressing the meaning of virtual experiential archaeology in the context of this paper, it is necessary to provide a definition for VTT. VTT, in the context of experiential archaeology as explored in this article, can be defined as: The use of technology-mediated experience in which the user is effectively immersed in a virtually reconstructed archaeological site or a mixed-reality environment inhabited by intelligent and life-like agents, and governed by the approximate laws of the material world so that the user could relive the experiences of past societies within the interactive VE. Such an environment, if properly implemented, could aid archaeologists in interpretive archaeology via the experiential approach.

3. Technology supporting VTT

Based on the definition presented previously, this section examines the possibility of experiential archaeology with the present state of VTT related technology. Fig. 1 is a diagram illustrating the current state of technologies that are relevant to VTT. The subjects of the figure separate technologies into five components based on sections 3.1 to 3.5 with subsections for detailing the information. Four states are provided to depict the readiness of technology. The "Primitive" state refers to technology that are in its initial stages of development, this may refer to new technology or technology that has not been properly developed for use in VTT. The "Developing" state refers to technologies that are being researched. Technologies positioned in the "Advanced" state are applicable to VTT – they are believable and provide a sense of reality that models to a level of accuracy various aspects of the real world. "Established" refers to technologies that can be readily applied in VTT.

3.1. Computer Graphics in Archaeology

Since 1973, the proceedings of Computers and Applications in Archaeology [33] begin congregating researchers working on early computer applications in archaeology. During the 1990s, topical research areas such as "GIS and Evaluation of Spatial Patterns", "Visualisation of Archaeological Data", "Image Processing", and "AI" appeared in the same proceedings [34]. In the mid 1990s, Internet applications for archaeology began to appear and became widely popular for archaeological research in 2000. At the same time in mid to late 1990s, advances in Interactive CG made possible some of the first attempts in the "virtual modelling" of heritage.

This advancement owes its successes to early attempts at 3D computer modelling. Realising that in situ analysis of the structure of an archaeological formation can be fraught with many difficulties from vegetation cover, sunlight, topography and inaccessibility of the site, not to mention the destructive techniques of earlier excavations, researchers in the 1980s begun exploring new approaches for archaeological analysis. In the early attempts, aside from aerial surveys [35,36] and remote sensing techniques, researchers begun experimenting with archaeological systems encompassing not only database capabilities but also ventured into 3D graphics visualisation [37–47]. However, the approach in 3D graphics methods in the 1980s was only capable of computing very limited portions from a site. Even so, it was discovered that 3D graphics with database capabilities has advantages over aerial surveys as obstructions such as vegetation canopies need not be rendered in 3D space, thus preventing site features from being obstructed from view. Developments towards the latter part of 1980s also saw the potentials of 3D graphics in archaeology, particularly on the medieval land divisions in the Isle of Man [47], and that advanced graphics techniques could have an impact on the analysis of survey data [46].

Interactive virtual worlds require real-time graphics. A survey of realism in real-time CG from the year 2000 onwards has surpassed what the CG community called the synthetic look. Real-time renderings of 3D models such as objects, scenes, buildings, effects, and even virtual avatars (representations of people) are now visually indistinguishable from its physical counterpart (see [48–52] for some related examples). This is made possible with the advancement of tools and technologies in the CG arena. 3D modelling and animation tools such as Autodesk's Maya and 3D Studio Max, and Pixologic's ZBrush not only makes it easier to build scenes and 3D models in archaeology, but also provides animation capabilities to "give life" to the models. One of the features is the toolsets for character rigging – the process of mapping the hierarchical set of

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Fig. 1. Diagram depicting the current state of technology for application in Virtual Time Travel.

bones (skeleton) to the 3D representation of a character (skin). Such tools make it possible to create humans, animals, birds, marine life, and insects for populating a virtual archaeological world. Graphics engines then interpolate the animation so that the transition between each animation appears natural. New developments in procedural/generative geometries enhance the animation and behaviours of virtual characters (e.g., Spore Game by Maxis). Procedural animation contrasts from predefined animation. Procedural animation generates animation in 3D models in real-time to allow for more diverse movements of a virtual character. Many graphics engines also support realistic texture mappings (bitmaps that wraps around 3D geometry) that can represent any materials, textures and colour. Shaders – for defining the surface properties of a 3D object, bump maps and normal maps allow the representation of any variety of surfaces and effects (materials, bumps, textures, dirt, imperfections, etc) without compromising on the resources required if geometries were used for describing all the textures or details of imperfections – imperfect CG surface textures associated with the natural look in physical objects. Furthermore, new techniques for texturing [53], shadowing techniques [54], and the introduction of pixel and vertex Shaders [55,56] have not only increased the realistic visualisation of virtual objects, but also reduced the often large resources required from the graphics processing unit.

If high definition archaeological representations are required, 3D high-resolution laser scanners [57] that digitises in colour are now available. This is useful for digitising sites that are still in existence.

3.2. Interactive Environments

The advent of Interactive Digital Media (IDM) has revolutionised communications and has provided new ways of disseminating information in all possible fields where concepts and ideas requiring a higher level of expressions are needed. Unlike the unidirectional media afforded by text, pictures, audio and video, their combination with new media types such as interactive 3D (i3D) and the research in HCI has reached new heights for effective interactive communications. Interactive media not only allow users to receive thoughts from the medium but also empower them to actively participate in the use of the media. The levels of interactive participation covered below refer to a user's total experience of an IDM application. From observations, IDM can be categorised into at least four main levels of participation:

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- selective interactivity;
- participatory interactivity;
- contributory interactivity;
- causative interactivity.

In Selective Interactivity, users are allowed to choose a number of given options in the media but does not contribute to it. Information websites in the World-Wide-Web (WWW) and many educational media such as Encyclopaedia CDs belong to this category. 3D viewers allowing a visualisation-only capability of any object or scene can also be part of this category. In Participatory Interactivity, users actively participate in a two-way communication. Interactive story-telling where the user participate in a conversation-style interaction with a virtual avatar for site information belong to this category. Other examples are Web forums and discussion boards. Selective and Participatory Interactivity may be grouped as one. In Contributory Interactivity, users are allowed to contribute directly to the shaping of the media. Wikipedia, the online encyclopaedia that allows anyone visiting the site to contribute to the content is a good example. Virtual worlds that allow users to contribute to its content can be posited in this category. In Causative Interactivity, the passage of time and the actions of users can have direct impact on the evolution of the media. The more recent computer games and evolvable virtual worlds stand in this category. This type of interactive VE usually contain some form of agents with intelligence or characteristics of life that response to user interaction. The user-actions performed in the world helps shape the community and environment of the virtual world.

Most VR platforms, graphics or games engines now support Newtonian physics, collision detection, and collision damage. Things move, fall, slide, and are damaged when hit by other objects or avatars based on their size, volume, weight and frictions on the surfaces they have and are sitting on. Special effects such as particles for fire, snow, rain, and natural effects such as wind, thunderstorm, and even tornado are now part of the interactive environment (e.g., Alan Wake). Vehicles and in-game objects are all destructible when strike upon by other objects. These next generation games have revolutionised VE, making them truly causative. These advancements can be applied increasing the realism of virtual experiential archaeology.

3.3. Enhanced Virtual Environments

An important feature considered lacking in virtual reconstructions of archaeological sites, if not in present VE research is the addition of "living" and "responsive" avatars and agents. This includes an environment that mimics climates and a weather system that virtual agents interact with. Most reconstructions involve non-interactive media and simple walkthroughs of a site. For example, Stone and Ojika [58] stated that VR users demand more and more in terms of interaction, participation and content, not just simple walkthroughs. Thwaites' [59] analysis of Ville de Quebec suggests that *Samuel de Champlain* be introduced as a virtual avatar in order that users could learn the history of the city from him, and that the potential of this aspect of Virtual World Heritage is currently a missing element in most, if not all Virtual Heritage projects. In fact, the VR community shared the same thought. Luck and Aylett's survey [60,61] of the applications of VE showed that the use of AI and Artificial Life techniques in VE can provide a valuable and effective way for research within specific application areas and that some researchers in the field of VR and CGI seek to progress beyond visually compelling but essentially empty VE to incorporate other aspects of physical reality that require intelligence or agents with characteristics of life.

Virtual characters in computer games endowed with intelligence are beginning to change the contents of virtual worlds. Virtual characters now possess the ability to learn and adapt using AI techniques such as Neural Networks [62] – a technique to simulate the processes of the human brain, Genetic Algorithms [63] – heuristic search methods based on natural selection, and Rule-based AI, they make decisions based on Finite State Machines – the model of behaviour based on states, Bayesian Techniques [64] – probabilistic, and plan travel paths via path finding algorithms [65]. Characters are able to socialise and form groups and networks. While research in AI attempts to model the human intelligence, research in Artificial Life [66,67] synthesises life and provided a framework for modelling a variety of life forms for populating a virtual world. These virtual organisms reflect the traits of their biological counterparts, allowing them to grow, reproduce, adapt, compete, and evolve. Algorithms have already been implemented for mimicking the flocking [68] and schooling behaviour of animals, birds, fish, and static organisms such as vegetation [69–71]. Virtual organisms can also adapt [72], and evolve [73] in virtual worlds that simulate the natural climate and environmental parameters [69,71].

3.4. Multi-user Environments

The sense of presence sometimes requires more than one participants within the virtual world [23,24]. The speed of networks and optimisation algorithms have improved to such an extent via online-gaming and social-networking that more than 1,629,589 users can be logged on to the network over a period of time [74]. The World of Warcraft, a MMORPG has more than 500,000 logged on at any given time [75]. Furthermore, clients (local installation of software) for such games process information locally on the users' PC, communicating only necessary information via the network. This frees up large amounts of bandwidth for Voice Over Internet Protocol (VOIP), which allows users to communicate within the virtual world, replacing text-based communication in older generations of games. Multi-user environments allow users to take on the role of any characters; this affords a very good platform for archaeological interpretation of social issues in anthropology.

3.5. Involving the Senses: Mixed Reality Technology

Howard Rheingold [76] first introduced a multisensory, immersive experience with Sensorama in the 1950s which has body tilting, stereo sound, tracks for wind and even aromas that were triggered at various points on a virtual bicycle ride

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through Brooklyn, New York. Research has improved since then. Although it is generally thought that involving the five senses can create a richer experience of immersion, no research has been conducted to quantify the results.

3.5.1. Olfactory

Barfield and Danas [77] defined a virtual olfactory display as "a collection of hardware, software, and chemicals that can be used to represent olfactory information to the virtual environment participant". The sense of smell (olfactory) can improve presence via odour cues that can trigger reaction in the user [78]. For example, Caster [79] developed a fire fighters training VR system that produces odours and radiant heat cues. Special devices that can track individual users before shooting an aroma directly at their noise via an air cannon has also been developed [80]. Real-time blending of scent has also been developed [81]. A review of virtual olfactory interfaces can be acquired from Davide et al. [82].

3.5.2. Auditory

Audio can also enhance the sense of presence if coupled with visual displays. Stereo and 3D spatialised sound systems [83] can synthesise both ambient and feedback sound. Spatialised sound systems, based on either a set of speakers or surround sound systems, or coupled with a Head Mounted Displays (HMD) control the amplitude, phase, and frequency of sound to create the sense of dimensionality.

3.5.3. Haptic and Force Feedback

There are many VR interfaces for simulating touch and force feedback [84]. In the archaeological context, among the more useful interfaces are haptic gloves [59,85–100]. A haptic device increases the simulation realism during virtual object manipulation and enhancements to the typical VR simulation. Developments may provide physical modelling, which replicate contact forces, surface deformation, rugosity, object weight, and etc [101]. Contextual clues about an object's material, shape, size, texture, and weight configurations have also been developed [102].

3.5.4. Augmented Reality and Mixed Reality

The survey of the development of virtual sense in the preceding paragraphs covers olfactory, auditory, and force and touch feedback technologies. But these could easily be replaced by Augmented Reality (AR) and Mixed Reality (MR) [103,104]. According to Azuma [105], AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space". Recent advances in AR allows the following properties [106]:

- combines real and virtual objects in a real environment;
- runs interactively, and in real time;
- registers (aligns) real and virtual objects with each other.

But are not restricted to particular display technologies nor the sense of sight.

It may include hearing, touch and smell. The capability to project or superimpose virtual objects in the physical world via HMD could prove to be very useful to experiential archaeology, by mixing digitally reconstructed ancient artefacts, monuments, and landscape objects within an archaeological site or similar environment, users could experience both the real environment and the virtual past, excluding the need for additional bulky equipments. A mobile AR unit is generally composed of a HMD, Global Positioning System (GPS), a mobile CPU, and a site information server hosted in alternative locations that communicates the site information to the mobile AR unit, such as ArcheoGUIDE [107].

3.5.5. Global Positioning Systems

GPS has been widely used in satellite navigation and the costs associated with setting up a unit for VTT-type heritage projects are inexpensive. However, except for ArcheoGUIDE, it has not been implemented in other projects. GPS receives precise microwave signals from between 24 to 32 medium earth orbit satellites in order to pinpoint the user's current location. GPS coupled with mobile AR devices could allow users to roam an archaeological site while virtual buildings, artefacts, and inhabitants are blended with objects in the real-world via a HMD, such as in ArcheoGUIDE.

3.5.6. Environment Sensors

Environment Sensor Networks [108] comprises an array of sensor nodes and a communications system which allow their data to reach a server that manages the data. The sensor nodes are connected and gather data autonomously. Typical sensors retrieve temperature, humidity, light, pH, proximity, vibration, and etc. A list of different Environment Sensor Network, their type, sensors, and scale can be acquired from a review by Hart and Martinez [109]. The sensor nodes may also be wireless [110] and can be attached to a human body [111] for various purposes. Sensor technology can contribute to a heighten sense of reality. Environment sensors could channel data to a virtual world that uses it to simulate climate and weather conditions that can affect the inhabitants of the world, such as virtual agents and Artificial Life. Wireless sensors can also be integrated with mobile AR units for simulating Mixed-Reality effects such as superimposed environment (rain, snow, and etc). Body sensors can measure physiological changes while the user is in virtual experiential archaeology.

4. VTT in heritage applications

Attempts at VTT in archaeology are scarce, but are beginning to appear with the advent of Virtual Heritage (VH) research. Full VTT experience is limited, and quantifying the user experience within virtual experiential archaeology is basically non-existent as of now. Nevertheless, this section provides case studies of partial VTT systems and related developments in the context of this paper in three main areas: natural and cultural heritage such as monuments and landscapes, the intelligent and living entities

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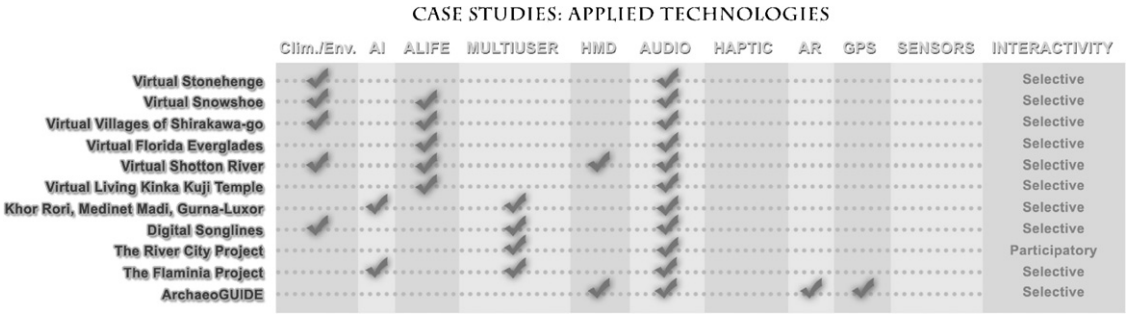

Fig. 2. Diagram depicting technologies used in the case studies presented in this article.

within them, and multi-user VE. Projects that use other Mixed-Reality technology are few and at a primitive stage and are not included in the case studies. Fig. 2 is a diagram depicting the various technologies applied in the case studies. Case studies involving intelligent agents are not listed in the chart as they do not include other technologies. The chart shows that haptic interfaces and environment sensors were essentially non-existent in these projects.

4.1. Natural and Cultural Heritage

The UNESCO World Heritage [112] defines heritage as "our legacy from the past, what we live with today, and what we pass on to future generations." Amongst which consists of Natural Heritage and Cultural Heritage. A good definition of Natural Heritage is the "natural features consisting of physical and biological formations or groups of such formations" or "Geological and physiographical formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of outstanding universal value from the point of view of science or conservation" [96]. Cultural Heritage includes the intangible qualities of a society and the physical artefacts that are associated with it. This section surveys potential projects that uses CG technology for virtual experiential archaeology.

A survey of VH research related to landscape reconstructions and VE inhabited by living entities that has potentials for VTT found a little more than ten examples, although the reconstructions of monuments for walkthroughs (e.g., [92–95]) and the piecing together of artefacts (e.g., [98,99]) for conservation are abundant. This may be due to the fact that VH research really only began in 1995 when the Virtual Systems and Multimedia (VSMM) Society conference was formed in Gifu, Japan [113]. The other reason is that projects in these categories are scarce – there are not many Snowshoe Mountains available, and Stonehenge is unique in both time and space. These projects are also difficult to implement due to the limitations of technology in the past and the lack of personnel with required expertise. In recent years, however, software and hardware technologies for visualisation and content creation are becoming inexpensive and more available. Furthermore, user-oriented programming languages, software libraries and environments for generating 3D contents have eased the creation of interactive VE. This section provides individual case studies of VH projects within the context of VTT.

Virtual Stonehenge [102] was constructed for immersive kiosk-based demonstration. The optimised surface representations of each of the 80 stones and both the surrounding topography were built up manually from point data extrapolated from hundreds of stereo and aerial photographs, plus geographical and photogrammetric information generated in 1995 by English Heritage. With the heritage site protected from public access, English Heritage saw VR as a possible solution to allow people to "walk" amongst the stones and experience the different textures and features in 3D, or be able to see the different lichens, the sword blade damage inflicted by Roman centurions and even graffiti carved in the form of a stylized signature by the famous architect, Sir Christopher Wren. The Virtual Stonehenge used Sense 8's WorldToolKit targeting the Intergraph platform with a VR4 headset. The simulation rendered an accurate night time sky by projecting the star positions onto a sphere surrounding the Stonehenge model from the celestial equator. Stonehenge first introduced the real-time sunrise effect into a VE.

Virtual Snowshoe [112] is an enhanced environment that uses real-time information to support the modelling of large-scale ecosystem climatic conditions based on live weather information and GIS terrain data. Refsland et al. defined an enhanced environment as "a mixture of virtual and real environmental information that is interconnected to provide a more realistic and meaningful interpretation of both the virtual and real environment that is ultimately greater than the individual experience", and discussed five major elements considered enhanced:

- real-time, enhanced information;
- reduction in storage;
- reduction in computational resources;
- natural pulses and Rhythms;
- hybrid Integration of Visualisation-Simulation, Artificial Life, Game Industries, and Real-Time Environmental Interactivity.

Three obstacles are given in the move towards an enhanced environment:

- insufficient computational power;
- non-engaging, Non-immersive;
- static environments.

Virtual Snowshoe uses Epic's Unreal™ games engine for the simulation within a common multimedia PC. The terrain

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is created from the conversion of a Digital Elevation Model (DEM) into heightmaps typically used for terrain generation in Unreal. Seasonal conditions of the landscape textures are colour-correction copies from aerial images from the National Aerial Photography Program (NAPP). Climate controllers are Web-based and integrated via HTML with SQL as a database and Macromedia's ColdFusion™ as the language. The sun controller has three modes: Real-Time, auto-step, and manual. The simulation uses several Web-based real-time streaming data sources for establishing streaming information related to weather, hydrology, snowfall, temperature, snow coverage, and slope conditions.

The Virtual Villages of Shirakawa-go [96] propose environmental simulation of weather to see the long-term cause and effect of climatic conditions and to observe what the dynamical representation of the effects of snow and wind have on the Gassho-Zukuri House. Shirakawa-go is located within 45.6 hectares of land in northern Gifu Prefecture and is one of the sites registered as UNESCO's world heritage. For the virtual reconstruction, the project was created in three parts: The panorama of Shirakawa-go and its surrounding area, the Minkaen part, an area within Shirakawa-go that occupies approximately 5.8 hectares, and a detailed view of a typical Gassho-zukuri house in Minkaen. The 45.6 hectares of the landscape were created by generating 3D models and textures from aerial photographs taken from an altitude of 22,000 metres. 3D Minkaen was created using drawings to establish the area's geographical data and colour images from aerial photographs, taken from a helicopter at an altitude of 750 metres was used as textures. An evaluation function technique was used for optimising the 3D terrains into a real-time capable model. In the third part, the interior and exterior of the 3D Gassho-zukuri houses was constructed. Two proposals were made for the environment. For environmental simulation, the first proposal considered artificially changing the geographical configuration and climatic conditions of the area. For the second proposal, dynamical representation of the effects that snow and wind have on the Gassho-zukuri houses is considered.

Virtual Florida Everglades [114] aims to create a cost-effective, freestanding VR simulation using the Unreal engine in a standard PC Windows NT/98 platform. The Everglades National Park is a 1-million acre park in Florida, USA; only parts of the Everglades were simulated using the atmospheric effects in the engine. The project attempts to create the illusion of "being there" by introducing a panoramic display with a bench-type seating arrangement. The simulation controls an airboat vehicle via a controller.

The Virtual Shotton River [69,70,115] in the North Sea Visualisation Project attempts to reconstruct, based on seismic datasets gathered while oil prospecting, a submerged Mesolithic landscape that once thrived with life and was a habitat and a land bridge for Mesolithic men [116]. The project models vegetation communities and their distribution over the landscape and uses a games engine to visualise and explore the surroundings. Researchers wishing to "go back in time" to the Mesolithic landscape could now navigate and interact with the physics bound objects, walk among the trees that have been artificially grown, access hazel shrubs for nuts, sit by the crackling fire, scout the banks for fish and clams, and to dwell in the 17 feet houses, thus enabling them to explore the past [117]. The project is ported into different systems using a Head-Mounted Display and a standard monitor [116].

4.2. Living Entities in Virtual Environments

The inclusion of intelligent entities in a VH site promotes the experience of presence. This section reviews projects that introduce AI and Artificial Life into virtual humans and representations of biological life.

Work has been carried out on animating certain forms of living beings as inhabitants of VE. Strictly speaking, an entity residing in a virtual world that is considered "living" should at least possess some characteristic behaviour that allows it to respond to the environment as any natural organisms would from other living entities or user interaction. However, a virtual entity that has the capability of responding to physics-based simulations, although responsive, cannot be considered as part of this category. For example, a ball that rolls down a virtual terrain as a result of user interaction cannot be in the same category, neither can a bell that gives a sound when its associated button is pressed. In VH, a living entity must in the least have "life", appear to be living, or possess the simplest intelligence that enables it to make uncomplicated decisions. In this case, virtual birds that flock together and "flee" from threats can be considered "living", so is a real-time virtual character that accomplishes certain tasks in his/her task environment. More advanced virtual life forms are those that grow, mate, reproduce, compete, survive, evolve, and cooperate with other organisms. Nevertheless, some projects that incorporate non-responsive avatars are also mentioned here. This section reviews research in "living" VH environments.

The Virtual Living Kinka Kuji Temple [97] uses the Unreal games engine as a simulation platform for the Virtual Environment. A behavioural module was developed for polling company stock price data to give position and behavioural information to Artificial Life entities in the Virtual Environment. The simulation uses the natural computing power of emergent properties and chaos found in live data streams (NASDAQ stock market) to enliven the artificial fireflies inhabiting the neighbouring gardens of the Virtual Kinka Kuji Temple based in Kyoto, Japan.

Virtual Snowshoe [112] used the NASDAQ stock market for the simulation of living entities. Using the Unreal engine, an existing actor class was used to create virtual birds that were integrated into the system with a complexity-based rule set that defined weather conditions conducive for flight. For more natural behaviour, data from the stock market was polled every minute to dictate how "energetic" the virtual bird will be – positive for energetic, and vice versa.

In Virtual Florida Everglades [114], the extensible subsystem of the Unreal engine using Object-Oriented C++ was used for making behavioural changes for characters in the engine. The 3D egret created in external modelling package and imported into Unreal uses state programming models for simple behavioural patterns like foraging, patrolling, sleeping, etc. Environmental triggers and a simple random seed algorithm was used to

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determine which patterns manifest themselves and predetermined player-attitude models (friendly, hostile, and reclusive) control other factors of the character. The addition of the virtual egret and a simple behavioural model adds reality to the simulation.

Ch'ng and Stone [69] introduced the concept of virtual plants in VH for solving the mystery associated with a large submerged landscape in the North Sea. Ch'ng's adaptability measure [72] and Artificial Life-based algorithms was used for determining the habitat of prehistoric plants that once thrived in the land bridge that connects main land Europe with the British Isles. Experiments using the Artificial Life framework yield evidence of correlations between the artificial vegetation and their natural counterparts. The virtual plants, which consists of the major species impacting the formation of the land-cover include the generic model of customisable vegetation lifecycle that corresponds to different vegetation types (trees, shrubs, herbs, grass, etc.) with seasonal differences (evergreen, deciduous). Competitions amongst plants for resources are determined by their canopy, density of leaves, height, and vegetation types. Plants are also affected by ecological factors and resources such as sunlight, temperature, carbon dioxide, altitude, soil, and hydrology.

4.3. Intelligent Entities in Virtual Environments

The addition of virtual avatars – representation of users of a Virtual Environment or characters inhabiting the environment has become quite popular in recent years. An example is Virtual Notre Dame [118] which created avatars – virtual monks using the Unreal engine that were intended to guide visitors around the cathedral, leading them to places of interests. Two other works based on single tour guide in cathedrals are Frohlich et al. [119] and Behr et al.'s [120] virtual cathedral in Siena. Others such as Foni et al. [121] and Papagiannakis et al. [122] added a small number of worshipers into virtual mosque. Sanders et al. [123] reconstructed the archaeological site of the Northwest Palace of Ashur-nasir-pal II, incorporating a 3D avatar of King Ashur himself for presenting the historical information of the palace. Song et al. [124] recreated Peranakans – descendants of an early Chinese community that evolved as a result of intermarriages between early Chinese settlers and the indigenous Malay in the Malay archipelago since the 17th century. The Virtual Peranakans were built to guide visitors through the environment and provide historical information. A project that simulates real-time character animation and dynamics in ancient Olympic games uses virtual athletes [125]. Although the virtual athletes appeared living, they were non-responsive avatars. However, the users could themselves participate in some of the games, which use simulated aerodynamics.

Simulations of crowd in large settings have also been developed. Ryder, Flack and Day [126] implemented an adaptive crowd behaviour system for aiding real-time rendering of a cultural heritage. The approach develops an algorithm that influences crowd dynamics to maintain a rendering frame rate in Boids-based self-steering crowds. However, the virtual humans have a limited understanding of their environments, such as differences between the road and a pavement, which when developed, will aid realism to the project. Ulicny and Thalmann [127] presented a 3D animated crowd performing virtual prayers. Ciechomski et al. [128], on the other hand, developed a reactive behavioural engine to simulate large crowds in a virtual audience. In the virtual audience, characters possess different emotional states, social classes, and genders.

4.4. Multi-user Virtual Environments

According to Steuer [11], and Biocca and Levy [25], the ability to interact with large number of groups as in a multi-user, VE may lead to even greater presence. Multi-user VE for exchanging cultural and scientific contents are scarce, not to say the implementations of it for experiential archaeology. Below are four related VTT projects.

Pietroni and Forte [129] is in the progress of implementing an offline scene editor and an online visualisation engine using Mult-User Domain (MuD) constructed through a web VR system for accessing three archaeological sites: Khor Rori, Medinet Madi, and Gurna-Luxor. Users communicate via an avatar in the virtual space through chat (dialogue) and interact with cultural objects.

The Digital Songlines article [130] provided a software toolkit for the collection and sharing of indigenous cultural heritage knowledge. The system communicates cultural information through a Multi-User Virtual Heritage Environment (MUVHE). The tool uses a game engine approach which allows the ability for setting weather, time of day, or progressive time, add flora and fauna related to the area from a database of objects, ambient sounds (wind in trees, bird calls, etc.), audio voice-over for locations of cultural significance, and an educational framework for accessing cultural materials within the environment.

The River City Project [131] is a multi-user virtual environment for teaching scientific inquiry and 21st century skills in middle school science classes. As visitors to River City, a town besieged with health problems, students travel back in time, bringing their 21st century knowledge and technology to address 19th century problems. Students, using the multi-user environment, work together in small teams to help the town understand why residents are becoming ill, manipulating variables to help determine the cause of the epidemic. Students collect data, form hypotheses, develop controlled experiments to test their hypotheses, and make recommendations based on their findings to other members of their research community.

The Flaminia Project [132] applies storytelling – an interactive system based on narrative techniques and metaphor, virtual characters, avatars, speaking objects and game dynamics and rules to make the space "alive". The other core concept is the introduction of MuD which encourages a collective and shared communication of cultural contents. In an example, the "Villa of Livia", avatars meet characters and objects belonging to the present time and help them to discover and visualise contents connected with the interpretation of the rooms: their structure, their chronological phase, their history and functions and their relations in the context of the ancient villa, some news about the people that lived there in the past.

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5. Conclusion

Since Ivan Sutherland [133], the Father of CG first defined the field which developed into VR, his vision of the Ultimate Display for the most part, is being realised: "Display as a window into a virtual world, improve image generation until the picture looks real, computer maintains world model in real time, user directly manipulates virtual objects, manipulated objects move realistically, immersion in virtual world via head-mounted display, virtual world also sounds real, feels real. . .".

VTT for experiential archaeology is becoming possible via the advancement of technology. From the trends of technological developments and the application areas which we have witnessed, it will not be long before the ancient past is brought back to life. Archaeological sites which are no longer in existence or are inaccessible due to time and space could now be accessed by anyone and at anywhere, simultaneously, either via VR over computer networks, or by participation via AR on the site of discovery. A scenario could be constructed where researchers could gather at a virtual site, taking on the role of a certain person in the past (virtual acting), or of an animal, carrying out their daily tasks while other researchers observe and interpret the scenario. Users of mobile AR donning a partly transparent HMD could be physically present on a site while ancient monuments, forests, and artefacts are superimposed on to their surroundings. Multiple VR and AR users could be virtually and physically "present" on a site while GPS tracks their locations and communication is conducted via VOIP. A master controller could increase the temperature sent by environment sensors while users, virtual avatars and virtual animals experience changes in the Virtual Environment and take steps in order to survive the changes. Predefined virtual representations of archaeological artefacts can be "picked up" via haptic interfaces and placed elsewhere for other users. A hunter-gatherer scenario could be set up so that virtual weapons and tools are used for hunting and gathering food from pre-programmed virtual animals, plants, and seafood. Virtual agriculture where Artificial Life-based plants grow based on data retrieved from environment sensors may be another scenario. Such VE will truly be causative and evolvable, much like the real world we live in except for the time and place of the historical setting, it is attempting to simulate. The capabilities of these technologies and its implications for research and for educating the public are massive and are only limited by our imagination.

In fact, except for the simultaneous engagement of all the five senses due to the present technological limitations, VTT could in the near future provide for more of an enhanced experience of a historical setting than physically-based experiential archaeology. An argument that supports this assumption is that all physical matter, including living beings, can be recreated digitally in the virtual world up to a point where it looks real, sounds real, smells real, and feels real.

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