‘Tangible Pasts’: User-centred Design of a Mixed Reality Application for Cultural Heritage

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Abstract:
Tangible Pasts is a Mixed Reality (MR) prototype that combines a tangible interface with virtual content. The physical object, a book, enables users to manipulate the virtual models in real time by their actions performed in the physical world. This paper presents an overview of designing the prototype, and the evaluation of this application by participants who tested its usability and interpretive value. It also presents some preliminary results of the second round of design and evaluation. The attention is stressed on the importance of performing constant user evaluations in parallel to the design of the prototype in order to produce an application that is usable and of benefit to archaeological research and interpretation of cultural heritage knowledge.

Keywords:
Tangible Pasts, Mixed Reality, Iterative Design, User Evaluation

1. Introduction

This paper presents the preliminary results of a tangible prototype interface for cultural heritage dissemination in a Mixed Reality (MR) environment. This research project was developed in parallel to our research work, which is related to several aspects of computer visualisation, interpretation and presentation of archaeological material, with the purpose to explore available MR platforms from a human and user-centred perspective. The design of this application, which utilises available technologies, was structured around three main research questions: a) How can we provide an intuitive user-friendly application for cultural heritage, which blends virtual imagery with the actual world, where users operate and interact with the information? b) How effectively can archaeological information and visual interpretations of the past be disseminated through such technologies? c) How can user evaluations in early stages inform archaeological interpretive design? Based on the principles of iterative design the prototype was designed, evaluated, analysed, refined and re-evaluated. This cyclic process will continue until any issues identified by participants in this research will be kept at a minimum. This project will also employ new technologies as they become available to the public, attempting to smoothly combine the natural process of reading with MR content.

2. Background and Objectives of Tangible Pasts

A significant number of collaborative projects have already started to exploit the real potential of MR technologies and develop new methodologies in interpretive archaeology, cultural heritage sites and museums (Noh et al. 2009, Champion 2011). A considerable amount of work has also been undertaken on user evaluations for assessing the interpretive value and the technological development of applications, especially in museum contexts. Some of the most significant lessons learnt in such visitor evaluations is that the interactivity of systems operating in MR environments scores highly (Danks and Rodriguez-Echavarria 2007) and that novel interfaces can only become effective learning tools if the interface is easily understood by the users (Economou and Pujol-Tost 2007). However, there is little work on user evaluations for informing the actual interpretive design from
the early development stages, despite the fact that such evaluations have admittedly played a crucial role for future revisions both on the interactivity of systems and their interpretive content (Danks and Rodriguez-Echavarria 2007).

In attempting to address this issue, we draw on the design methodologies from disciplines such as Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW), where iterative design is adopted throughout the phases of prototyping, testing, analysing, and refining a product or interface (Rogers et al. 2006). In those fields, iterative design is mainly utilised for testing design ideas and interactions with a system prior to developing its hardware and software components; a notion which was pointed out in the early surveys of Augmented Reality (AR) research due to the inherent technical complexities of implementing such applications (Azuma et al. 2001). Paper and more recently video prototyping (de Sá et al. 2011) have been used to inform the design of AR applications. In this project, the research objectives were mainly concerned with the design of heritage content and users’ responses to the modalities provided by the system for interacting with CH information rather than the system itself. For this reason, we used an AR commercial platform and prototyped the tangible interface to test some initial ideas. Drawing from previous work on MR and the intuitiveness of Tangible User Interfaces (TUI), such as the ‘Magic Book’ described in Billinghurst et al. (2001), this study explores an alternative and interactive mode of engaging the public with archaeological information. It focuses on a multimodal approach for enhancing Cultural Heritage (CH) experiences by combining the interpretive nature of physical books with virtual CH content (Wright and McCarthy 2010).

Additionally, this work set out to investigate the benefits of exploring archaeological information in a MR environment and, to define and assess this environment in the virtuality continuum (Milgram and Kishino 1994). In this continuum, according to Milgram and Kishino, real environments are shown at one end and the virtual ones at the opposite. Augmented Reality and Augmented Virtuality (AV) are placed within the general area of MR, which is defined as the environment in which ‘real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum’. Renevier and Nigay (2001) provided a clearer distinction between AR and AV systems. According to their definitions:

- In AR, interaction with the real world is augmented by the computer.
- In AV, interaction with the computer is augmented by objects and actions in the real world.

Bearing in mind the above terminological discussion, this paper will define the environment of this application and demonstrate why from an interpretative design point of view it is important to choose the suitable environment for each application (Drascic and Milgram 1996).

3. Description and Content of ‘Tangible Pasts’

‘Tangible Pasts’ consists of 12 pages, which combine textual and visual information, three-dimensional models and animations in a single tangible interface, enabling the user to experience two prehistoric sites of the Minoan period, by turning the pages of the book and seamlessly moving between physical and virtual content. The book is divided into two sections: The first one regards the Minoan settlement at Zominthos, Crete; the three-dimensional models and the renderings presented in this section were produced as part of Papadopoulos’ research project (Papadopoulos and Sakellarakis 2013) to simulate the impact of natural and flame illumination in the ceramics workshop of the building. The first page provides users with basic
textual information for the archaeological site and the ceramics workshop, while the second includes two renderings of the settlement and the workshop as well as the marker that triggers the AR content (see methodology). This model employs basic illumination and textures due to the limitations of the AR platform used. However, it does not pose any constraints in understanding space and providing a sense of materiality. The third page provides a comparison between a photograph in the current state of preservation and the corresponding 3D model, while the fourth focuses on the potter’s wheel with both textual information and an AR model of a potter’s working bench, also including an animation of the turntable (Fig. 1).

Also, a digital museum for the finds unearthed in the ceramics workshop was constructed (Papadopoulos and Kefalaki 2010) in an attempt to work on different display combinations for the actual museum that will be erected in the future to house the finds of the excavation. In these two pages users can read about and also see in AR two special objects. The second part is related to Gournia, a Minoan town in eastern Crete, which is examined by Chrysanthi in relation to visitors’ movement and circulation patterns in archaeological sites. In this case as well, the principles of presentation are the same: basic textual information, photographs related to the site, and three-dimensional models, which were constructed by Frankland based on the principles of procedural modelling.

4. Methodology

4.1 Design

Our design methodology was based on the principles of iterative design (Buxton and Sniderman 1980). The ‘Tangible Pasts’ prototype was developed, tested and refined in order to improve its quality and functionality based on observations and users’ evaluations. The prototype consists of a tangible element, a book, and several intangible elements in the form of three-dimensional models, animation, video and sound. As far as the physical element is concerned, we attempted to create a usable book that would facilitate reading, as well as the presentation of the textual and visual information and the interaction of the users with the virtual content in a seamless manner. During the first design cycle, we used A5 sheets, devoting half of the pages to textual data and half to visual information and markers. The typeface used was Papyrus, intending to create a readable calligraphic hand-crafted look that fitted the textured paper used to print the content. Texts’ length was 170 words on average attempting to provide the basic information needed to contextualise the AR content presented. As far as the visual content is concerned, most pages included either two images of similar size or one larger image and the relevant marker. Regarding the latter, the limitations of the software used, made us employ preconfigured black and white markers, which are obtrusive elements in the process of reading.

Concerning the technical aspect of the prototype, 3dsMax 2012 was used for the production of the majority of the models and animations, while CityEngine was implemented for constructing alternative structural models of the Minoan houses at Gournia. The AR-Media 2.0 plugin for 3dsMax was
employed to assign markers to the virtual models and configure the scenes according to the page layout of the book. The prototype was initially tested by ourselves within the available functionalities of the plugin, while at the stage of user evaluation, the application was exported and presented by the standalone AR-Media Player developed by Inglobe Technologies. As far as the hardware is concerned, the workstation used had an Intel Xeon 2.67GHZ Quad CPU Processor, 512MB QuadroFX580 NVidia Graphics Card and 12GB RAM. The AR content was triggered by using a 1.3 megapixel webcam with auto-adjustment for low lighting conditions, positioned on a stand at the level of the head of a seated user, several centimetres behind his/her back. Lastly, the AR content was projected on a plasma screen and a keyboard was used for basic interactivity with the models.

Although AR-Media plugin could handle textures and a significant amount of polygons, the high-fidelity models already produced for another purpose had to be optimised for the needs of this prototype and the requirements of the development platform. All the physically accurate Mental Ray materials were replaced by standard textures, while the polygons of the scenes were significantly reduced, not only by optimising objects and surfaces, but also by removing unnecessary details and high-polygon objects. For example, in the ceramics workshop model, the amount of pottery was limited to such an extent, so as the reader/viewer would be able to understand the function of this space and the arrangement of objects within it. Also, an abstracted version of the architecture of the building was also created. In the case of Gournia houses, the models were produced particularly for this reason by employing procedural modelling, a script-based technique that uses ‘shape grammars’ to semantically describe 3D models (Müller et al. 2006). Based on this technique, we wrote a script that rapidly generated numerous 3D models that depicted differing levels of certainty in the archaeological data about the configuration and morphological features of the structures. The shape grammars were created based on construction rules and materials of Minoan domestic architecture (Preziosi 1983, Palyvou 1999, Shaw 2009). To present the different types of 3D models generated we used a pop-up animation approach where consecutive models pop-up from the pages and sink back into the pages giving way to alternative versions (Fig. 2).

4.2 Implementation and user-evaluation

It has been argued that the involvement of both expert-users and real-users in such early stage evaluations is ‘the most promising approach to evaluate interfaces of a complex kind, such as cultural
In parallel to the questionnaires, we observed users’ interaction with the prototype. Observing a user’s interactions with a prototype in a lab study is a typical HCI evaluation methodology. Although we did not employ these methods rigorously to evaluate our design against certain usability criteria, we did focus our attention on understanding how users chose to manipulate the book, how they responded to the triggering of the AR content and how their attention varied between the textual information and the analogue and virtual visual content. After testing the prototype, we conducted informal interviews with several of the participants, during which they freely described their experience and expressed their concerns. This also allowed us to follow up on the behaviours we observed the users engaged in, helping us to determine their intentions and whether our prototype fulfilled them.

5. Results of the User-Evaluation

The first user evaluation questionnaire was completed by 22 people ranging from undergraduate students to professionals in various fields of archaeological visualisation, with their ages ranging from 20 to 65. Although the sample was relatively small to draw safe conclusions about several aspects of this prototype, it was adequate to perform a prototype evaluation and inform the next stages of the design.

The users were asked to mention three things that they liked the most and three things they liked the least about the project. From the first question we arrived at six principal themes representing participants’ positive comments and revealing the strengths of the Tangible Pasts prototype. People commented positively on the interactivity that the prototype provides, mainly because they were able to move the 3D models in real time with their own hands, play with the animations and the 3D models giving them the ability to interact with the system and its content. This issue brings us to the second
In regard to blending real with virtual interpretive elements, participants also pointed out that they liked the fact that the prototype was not entirely computerised since it combined physical and virtual content. We also received many comments including words such as ‘mysterious’, ‘intriguing’ and ‘magic’, referring to the intuitiveness of the system to provide interpretation in an unexpected manner making the whole experience ‘engaging’, ‘playful’, ‘entertaining’ and ‘feeling like an exploration’. In terms of the technology employed, participants liked the way technology was appropriated to assist and stimulate interpretation via a common interpretive medium, a book, and referred to the use of technology as ‘intelligent’, ‘innovative’ and ‘unexpected’ having a ‘low tech meet high tech feel’. In terms of the actual interpretive content, people commented on particular aspects of the 3D models and their interpretive value, the alternative reconstructions available and the fact that models were accompanied by textual interpretation in case someone wanted to explore in detail the archaeological sites or finds.

On the other hand we obtained a valuable insight into the constraints and flaws of the prototype in terms of its interactivity, design, technology and the actual interpretation provided. A serious issue picked up by the analysis of the questionnaire, as well as our observations, was that people tended to focus more on their interaction with the 3D models and ignore the textual and visual information provided in the book. This also explains participants’ suggestions to use less text and bigger fonts, as well as to incorporate descriptions and explanations within the virtual display. The interpretation of this observation as a manifested tendency, especially in younger participants, to replace any analogue means of knowledge communication with more interactive and pleasing digital formats would only present one side of the same coin. The fact that the book contained a significant amount of analogue content was a design decision, since one of the main purposes of creating this interface was to shift the attention from the virtual and digital content to the physical environment, where users operate with the system while constructing their interpretations. This decision however, was not leveraged by the implications of the component technologies used to implement this application. More specifically, the use of the monitor as the display technology resulted by default in the shift of attention to the virtual environment (the monitor display) despite the fact that it depicted elements from the physical environment. The physical book and the user’s actions in the physical space are merely used to interact with the system (Renevier and Nigay 2001). Thus, it could be argued that the interaction takes place in the middle of the virtuality continuum, in a MR environment which is difficult perceptually to define whether it stretches towards AV or AR. Nevertheless, had we used AR goggles as a display

Figure 4. Table with the results of the evaluation on the prototype’s interpretive value based on four criteria: 1. Effectiveness of mixed media cultural heritage information dissemination, 2. The use of real and MR content, 3. Stirring imagination and evocation of senses, 4. Assessment of the storytelling flow.

<table>
<thead>
<tr>
<th>Overall Interpretive Value</th>
<th>0 Very Bad</th>
<th>1 Very Poor</th>
<th>2 Poor</th>
<th>3 Fair</th>
<th>4 Good</th>
<th>5 Very Good</th>
<th>7 Very Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture of text</td>
<td>6.5</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Images and 3D models</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Use of real and Mixed Reality (MR) content</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Stirring imagination and evocation of senses</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Assessment of the storytelling flow</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>
A few participants with a background in computer graphics commented on the graphical/virtual design approach mentioning the simplicity of some models. However, as mentioned previously this was not a design issue, but a technical one since current available AR platforms cannot support high fidelity models with physically accurate lighting and textures. Because of that, we decided to exploit this technological limitation to evaluate people’s responses to such 3D representations and address the long-debated discussions about photorealism and non-photorealistic rendering in archaeological interpretation (Frankland 2012). Finally, in terms of the interpretation we received some suggestions about how to enrich the narrative and include scenes from everyday life in a Minoan settlement. Some of the participants pointed out the importance to populate the virtual scenes with people and action in order to contextualise the sterilised and static interpretations.

Participants were also asked to evaluate the overall usability of the prototype both in terms of interaction and its effectiveness in cultural heritage dissemination. More than half of the sample stated that they found it very satisfying, while a significant percentage said that it was extremely satisfying as an interactive tool that can improve the dissemination of cultural heritage knowledge (Fig. 5).

It is also interesting to mention that men were in overall more enthusiastic than women and that only women answered that they found it neither satisfying nor disappointing. Lastly, it was important to canvass their responses regarding the interpretive values of the prototype (Fig. 4). The use of real and MR content, as well as the stirring of imagination and the evocation of senses was rated with 6 out of 7, while the mixture of text, images and 3d media and the storytelling aspect was rated lower with 5 out of 7. As this prototype was mostly visual, since tactility existed through the book itself, but not actual tactility related to the archaeological features shown, it is quite odd that a great number of participants ranked quite high the imagination and the arousal of the senses. As far as the mixture of the various media is concerned, the evaluation with 5 out of 7 is reasonable as the text that accompanied the illustrations and the markers was quite long, and only few people read it through.

Our observations, also confirmed that participants were discouraged by the amount of textual information in the book. The majority of them were reading the first couple of sentences, while others were skipping the longest pieces. This was especially apparent for the pages where the
virtual content was more impressive than the rest. In overall, it was noticed that younger people were more hesitant to read the analogue interpretations, due to their fascination by the technologies employed and the monitor display, while older participants were spending equal time to read the content and interact with the models, possibly because of their greater familiarity with more static pieces of information.

6. Refining and Re-evaluating the Prototype

The first user evaluation, as well as the observations and the discussions with the participants provided useful comments for the evaluation of our application in this initial stage. Their input was used for the improvement of the prototype in the second stage of development.

Participants’ positive responses concerning the ability of the application to stimulate the imagination and evoke the senses were a valuable find. As a next step we included sound, both in terms of narration and the sounds produced from the various features (e.g. potter’s wheel), contributing to a more sensory engagement with the datasets, as well as enhancing the storytelling flow. In addition, we significantly reduced the textual information within the book, which was replaced by virtual annotations explaining various features in the 3D models (Fig. 6).

Finally, we incorporated a video presenting the process of traditional pottery making, running parallel to the potter’s wheel 3D animation (Fig. 7).

The triggering of the markers, which were reduced in size to limit their visual obtrusiveness, is still implemented by the use of a web camera and a computer monitor, especially due to the high cost and the inherent limitations of new head mounted devices, i.e. goggles that currently exist in the market. In the next stage, we are going to implement our application with other platforms that enable image reference AR and use the actual images included in the book as markers, since they were only serving illustrative purposes in the application’s current configuration.

We have already started testing the new version of the prototype to a different audience to see the responses of people that are not by definition fascinated by any means of archaeological visualisation. The second call for the evaluation of Tangible Pasts was made to everyone within the University of Southampton and was not limited to archaeology specialists or humanities students. Although it is quite early to quantify the results of this second round of evaluation, some of the participants provided valuable comments, which are briefly discussed below.
The majority of them positively commented on the newly introduced features of sound and video. They particularly liked the mixture of different media and the combination of conventional sources of information (e.g. sound) with virtual content. An interesting comment that was not pointed out in the previous evaluation was that the interaction with the book and its manipulation in front of the camera provided a sense of three-dimensionality, perspective and depth which is not perceptible by using conventional means of representation. This may be due to the seated position of the viewers that allowed a more comfortable posture to move the book, in contrast to the first evaluation, where the configuration of the exhibition space only allowed a standing position, resulting in some difficulty to manipulate the book in relation to the camera and the computer monitor. However, it should be noted that a few of them found that the angle between the book and the camera as well as the constant adjustment of hands and posture in order to trigger the markers was uncomfortable and rather complicated. This also accrued from our observations during which we realised that users were often losing the markers from the camera’s field of view and as a consequence the AR scene was starting over. This was rather annoying for the narration and the video content that had to restart each time. The difficulties that participants faced were expected, since they had to balance the familiar practice of reading with a completely unusual process of moving the book and the body to trigger the markers and make the rest of the content appear. These problems would have been overcome by employing AR glasses, which would make the objects appear on the book and the users to follow the familiar process of reading without having to adjust their position to enable the virtual content. Therefore, the digital workspace would turn into a physical locus.

Our observations also pointed out that all participants were reading through the information in the book, in contrast to the first evaluation in which participants showed a preference for the virtual content. It should be noted that from a total of 22 people, only a few read the information provided. This is understandable, considering the fact that the second evaluation was undertaken in a controlled and noise-free environment, conversely to the first, which took place in an exhibition space with constant presence of people and buzz.

7. Conclusions

The majority of the responses showed that the application of MR technologies for the improvement of users’ experience and the enhancement of books’ interpretive nature is a challenging pursuit. However, technological limitations, as well as non-affordable AR devices and enabling technologies have not taken this paradigm into mainstream adoption. According to Gartner’s hype-cycle Special Reports (Gartner 2010, 2011), where the maturity, business benefit and future direction of technologies is assessed, in 2010 AR was at the highest level of expectations, while in 2011, the underlying issues had made apparent that the wider adoption of this technology will delay for about five to ten years.

Within the archaeological computing communities there have been vivid discussions concerning the virtual imagery produced as part of our research and the modes and technologies we employ for public outreach. Our role as humanities researchers is to keep working on how to efficiently make these technologies accessible to the public, while building a critical framework according to which such technological advancements are exploited for the benefit of archaeological research and dissemination. People’s responses seemed to encourage attempts of constructing aspects of the past and making them available to the public through novel computer methodologies. Our user testing and the feedback provided, showed that the continuous evaluation of such prototypes from a human and user-centred perspective, is an essential practice
that can potentially prevent the risk of producing an application that is of little value to the users and the wider academic and cultural heritage community. Besides, we hope to have demonstrated that early stage user evaluations cannot only be used to assess technological components of CH applications but to significantly inform archaeological interpretive design via such user-centric approaches.

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References


