EUROGRAPHICS Workshop on Graphics and Cultural Heritage (2017)
R. Sablatnig and B. Štular (Editors)

Short Paper

The fabricated diorama: Tactile relief and context-aware technology for visually impaired audiences

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Figure 1: *a) Vector graphic representation of the kittiwake "diorama"; b) 3D relief model generated from scene; c) 3D print of relief; and d) context-aware mobile application for enriching museum experience of visually impaired visitors.*

Abstract

The recent popularity of digital fabrication has stimulated cultural heritage professionals to utilise such technologies for a variety of processes, including the creation of digitally fabricated handling objects. The design and production of these objects or replicas, as commonly known, depends on choices that do not only limit themselves to a variety of technologies. This paper presents a focused contribution towards increasing the understanding of the heritage community on how to introduce digitally fabricated objects within context-aware museum experiences for different audiences. The purpose of the project is to enhance enjoyment, learning and appreciation of cultural and natural heritage while avoiding the "technological fetishism" which often appears along with the introduction of new technologies. In particular, the paper presents research focusing on the needs of visually impaired and blind audiences; it describes the development of a context-aware tactile experience within the Booth Museum in Brighton (UK); evaluates the developments with this target audience; and presents the preliminary results of the research.

CCS Concepts

•***Computing methodologies*** → *Computer graphics;* •***Applied computing*** → *Arts and humanities;*

1. Introduction

In recent years, digital fabrication technologies have become more affordable and easier to use. These developments have stimulated Cultural Heritage (CH) professionals to utilise such technologies for a variety of processes including conservation and restoration of movable and immovable assets, exhibition planning, loans, packaging, commercial uses, creative applications and processes related to access and education [NL13, SCP*14, NRRK14, SCP*15]. Digital fabrication technologies present immeasurable opportunities to customise and enrich the information provided by fabricated objects, while embedding in them different meanings and considering different needs regarding CH experiences [Cam10, SCP*14]. Nonetheless, there is a lack of knowledge of how different audi-

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ences perceive the properties of digitally fabricated objects in order to enjoy and appreciate CH in an "inclusive" way.

This paper forms part of a wider research project which aims to investigate how different "target" audiences respond to the use of fabricated objects and other interpretative media within a heritage experience, while acknowledging the contextual parameters of every case-experience. The paper focuses on visually impaired and blind people, who access with the support of a context-aware mobile application a fabricated environmental display of the Booth Museum. Visually impaired people have been chosen as one of the "target" audiences of the research, as they can benefit significantly from digitally fabricated tactile experiences. The paper is organised as follows. Section 2 describes the context in which the museum experience was deployed. Section 3 presents related work. Sections 4 and 5 present the development of the experience. Finally, sections 6 and 7 present the evaluation and conclusions.

2. The Booth Museum, Brighton (UK)

The Booth Museum was founded by Edward Thomas Booth in Brighton in 1874 to showcase his personal collection of environmental displays or "dioramas". These dioramas, which became very popular in the late 19th century, usually present taxidermic specimens (mostly stuffed birds) in a scene replicating their natural habitat. The scene is usually encased in a glass display with painted side and back walls. The main purpose of these displays in the Victorian era was to associate species to their natural surroundings and provide an "ecological" view of the natural ecosystems [Won93].

Nowadays, the Booth Museum mainly displays its dioramas stacked along its exhibition walls (see Figure-2); along with collections of minerals, rocks, insects, animal bones and other objects. The museum has a wide range of visitors but its management team is interested in making the museum's collections accessible to visually impaired people through the deployment of digital fabrication technologies.

Figure 2: *Exhibition of "dioramas" at the Booth Museum.*

Hence, the requirement was to develop a context-aware and tactile experience which could support the visually impaired audiences to access the otherwise non-accessible displays of the Booth Museum. One of the objectives was to design a -as much as possible- multisensorial experience by delivering tactile and auditive information. In addition, the experience should benefit visitors not only in terms of knowledge, but also at an engagement, attitudinal, emotional and behavioural level [DHU16].

3. Related work

3.1. Digitisation of dioramas

Photogrammetric methods, industrial scanners and depth-sensing devices like Kinect are typically used to acquire the shape of a heritage artefact. To our knowledge, there are no examples of environmental displays or dioramas that have been digitised in 3D and reproduced with the use of digital fabrication. This type of objects present reflections on the glass of the display making acquisition extremely difficult. Another difficulty is the encased nature of the exhibit which eliminates the possibility for a 360 or even a 180 degree acquisition. Lastly, even if the scene was not encased in glass, the digitisation and mainly the fabrication of birds, plants and other natural species is an issue that has not been solved yet.

3.2. Museum experiences for visually impaired audiences

In recent years there have been a number of projects that focus on the provision of multisensorial experiences which combine tactile explorations with auditive information. Several projects make use of digitally fabricated objects and multimedia content to support interpretation for visually impaired users. For instance, the "Orasis" project deploys Arduino boards, touch sensors and a mobile app to enhance access to museums for blind users [AA16]. A similar project at the National Etruscan Museum of Marzabotto (Italy) utilises 3D replicas, NFC technology and QR codes along with a mobile app to allow visitors to enjoy audio descriptions about the artefacts [3D 16]. Touch sensors on a "digital touch replica" of a cat sarcophagus have been used to trigger audio descriptions in a project by researchers in Austria and the UK [RSL*16].

Digitally fabricated reliefs have also been introduced to communicate relatively "flat" information, such as architectural facades, photos and paintings. The Tooteko app case study [DBGV15] deploys NFC technology (ring and tags) to provide audio descriptions of a 15th century church facade in Italy. A USA-based company named 3DPhotoworks produces coloured tactile prints of paintings and photos. Their prints for the "Sight Unseen" exhibition at the Canadian Museum for Human Rights have embedded touch sensors which trigger audio descriptions [Pho, Sig13]. In addition, the "Touch the Prado" exhibition in Madrid features coloured replicas of famous paintings along with audio descriptions [Hew15]. The "Out Loud" exhibition at the Andy Warhol Museum in Pittsburgh (USA) showcases tactile representations of artwork from Warhol and supports the tactile experience with audio descriptions that use location-aware technology and a dedicated mobile app [Bla16, Mor16]. A variety of tactile paintings in the form of relief have also been produced by the VRVis research centre in collaboration with the University of Vienna. These paintings include a system which uses a camera and gesture recognition (on and off the object) to provide audio descriptions for Klimt's Kiss [RFMP16b, RFMP16a]. Another system developed by [BCF*16] uses a Microsoft Kinect scanner to detect users' hand position with respect to a bas-relief and provide audio information.

3.3. Context-aware technologies in museums

Context-aware technologies are increasingly found within museums, where a visitor's personal context can help determine the best way to present and gather information about the artefacts on display. [CHG*15, SBU*17, CTH17] present various context-aware museum tour guides that use information related to the personal context of individual visitors. In these examples, the context is mostly used to adjust systems' recommendations and support visitors to learn and enjoy their museum visit.

4. Design and production of 3D model of relief

The selected diorama presents a kittiwake standing on a rock and gazing across the horizon (see Figure-3). Given the digitisation challenges, it was deemed necessary to work with a 2D image in order to extract information about the shapes of the contents of the display. Then, the scene could be presented in the form of a relief similar to other tactile material for visually impaired audiences.

Different workflows have been proposed for the creation of reliefs from 2D images. They use a variety of methods to extract contours, to segment parts of a picture/image, to control volume information and to simplify parts of the image [RMP11, CFG*12, FP13, LMTB13, FGV*14]. Essentially, the problem of automatically extracting contour information of a given image could be considered as a 2D segmentation problem [FKF16]. Nevertheless, the above methods generate too much information which might confuse a visually impaired user. In most of the above cases, additional manual work or "interpretation" is required to select and convey the most important elements of the scene.

The deployed workflow used a high quality image of the display. This was acquired with a DSLR camera by using a polarising filter and a piece of thick black fabric with an opening for the camera lens so as to eliminate reflections on the glass of the display. The raster file was imported into a vector graphics software in order to trace the most important elements of the scene (see Figure-1(a)). Some of the decisions that were made at this stage with respect to simplification were to present the kittiwake in a fully profile view (which is more easily understood by blind people) and avoid overlappings by omitting objects of the scene. The "Decision Tree" for the creation of tactile graphics was particularly useful during these processes [HS04].

The individual shapes were consequently imported using the Drawing Exchange Format (DXF) into a Computer-aided design (CAD) software to assign suitable heights for each shape [BC11, Per, RMP11]. Some of the key design requirements that were taken into consideration include:

- **Size reduction**: the relief constitutes a smaller version of the original diorama. There is a reduction of approximately 50% which was partly determined by the capacity of the printer's deposition bed and research from [OYS10].
- **Elevations**: most individual shapes on the relief (apart from the sound-wave and the bird's body) have a difference in height of 1mm with respect to the area where they "sit". Even though there is research indicating that recognition of map symbols can occur at lower elevations, this choice was partly determined by consideration of guidelines about minimum heights for symbol recognition [JSUS09, GP14, Bra08]. The body of the kittiwake has a height of 5mm as the purpose was to emphasize this particular shape. In addition, the eyes of the bird have been designed to be concave, as it has been suggested that this is a universal reference point for visually impaired people [Hew15].
- **Braille label**: this has been designed based on specific guidelines [Bra08] and it is placed at a distance of around 8mm away from the kittiwake [BC11].
- **Colour**: even though colour is important for some visually impaired groups, colour was not included in the relief due to: instability of materials; different colour recognition abilities depending on the type of visual impairment; limited capabilities for colour transferability on the flat surfaces of the relief; concealment of relevant processes [Hew15].
- **Texture**: texture information is not included in the relief mostly due to the lack of a satisfactory solution to represent feathers. Furthermore, depth information with respect to each element of the scene was not considered due to the lack of conclusive evidence to support clear design guidelines.

The relief also includes a 3D representation of the kittiwake's call sound-wave. This was created by tracing the sound-wave into a 2D shape and spinning the 2D shape around the Z-axis to form a solid which has rotational symmetry. The resulting model is shown in Figure-1(b). This was printed in a Stratsys Fortus 250mc 3D printer using ABS material. The final relief is shown in Figure-1(c).

5. Development of mobile application

A mobile application was developed to provide guidance on how to navigate the relief as well as information about the kittiwake and its call. An important requirement was to have a context-aware system that would alert and guide the visitor completely hands-free, so as not to interfere with the user's tactile experience.

The mobile application was developed using context-aware technology by deploying Estimote's proximity beacons. These 1-way hardware transmitters constitute a class of Bluetooth Low Energy (BLE) devices which broadcast their identifier to nearby portable electronic devices. Most modern smartphones constantly scan for these signals, when location services functions are turned on. Users are required to install an application on their phones prior to the museum visit. During the visit, when their smartphones enter the beacon's range, the mobile application triggers the audio description with further information on how to proceed.

Beacon ranging is used to measure the distance between the user and the relief. The distance is estimated through the "Received Signal Strength Indication" at the moment of scanning. The reason is that the mobile application should only trigger the audio when the user is at an arm's distance from the relief.

The audio file which contains information about the display, the location of the components on the relief, guidance and detailed descriptions of the individual elements as well as the actual sound of the kittiwake's call. As such, the user interface is very basic (see

Figure-1(d). It mainly displays an image of the kittiwake diorama and provides buttons to pause, play and start again the audio file. The application was developed using Android OS by deploying the Android and Estimote SDK.

6. Evaluation

6.1. Methods and participants

This research deploys the approach of case studies to examine digitally fabricated artefacts and how people perceive them within the interpretation process. A preliminary evaluation of the experience was carried out at the Booth Museum in summer 2017. In order to triangulate the data, the collection of evidence for this case study includes video recordings, observation notes, short questionnaires and a focus group discussion with the participants.

The pilot case study involved four partially sighted and blind participants. Half of the participants were men and half women. Most participants have some level of sight or memory of sight (in case of total blindness). Three participants were aged 60 years plus and were all using hearing aids. Participants were invited to explore the relief and diorama that were placed on a table (as shown in Figure-3). The presence of the beacon triggered the audio description. After the exploration (see Figure-3), the participants were asked to respond to a questionnaire about the features of the relief and the experience. The focus group discussion took place when all the participants had finished with the exploration of the relief.

Figure 3: *Evaluation setup and participant testing the application.*

6.2. Preliminary results

The overall feedback from the participants with respect to handling opportunities with the use of 3D replicas was very positive. Two of them stated that they have never had opportunities to handle objects in museums before and two mentioned that they handle objects sometimes. Nonetheless, the exploration of the 3D relief presented a level of difficulty for many of them and as one participant noted "this was a new venture" for him.

This was confirmed by the observational data, especially as most participants of the pilot study belong to an older age group and are not familiar with technology and exploration of tactile reliefs (three of them had never used technology in museums before). Therefore, users tended to focus mostly on the audio description of the relief and needed extra motivation or directions from their accompanying person in order to interact with the relief. The data also suggest that participants who are partially sighted still rely heavily on their visual capabilities and in many cases have not developed their tactile skills (especially those who became partially sighted at an older age). The only participant who identified himself as totally blind found it difficult to distinguish the contents of the relief, even though he possesses visual memory. The reason for this could be the novelty of the experience and the lack of exposure to tactile images from a younger age [Ell02].

All participants were "satisfied" or "very satisfied" about the audio description. Yet the observational data and the focus group discussion indicate that the navigation through the relief should include additional direct suggestions on how to proceed with hands positioning and exploration. The control of the audio on the mobile phone app allows people to pause and listen to the description at their own pace, but for people who are not familiar with these functions this might not be easily controlled.

Feedback from the questionnaire data suggests that most participants were satisfied with the size of the relief. On the other hand, shape recognition of objects with low elevation has been proven to be difficult for most users. Most users were able to understand the shape of the kittiwake whose body was elevated at a higher level. The participants found the texture of the relief to be smooth.

The opinions about the existence of colour were mixed, depending on the level of sight and type of impairment. Two of the participants could not see any colour, so did not comment on it. One participant mentioned that they would like the relief to have colour, whereas another stated that they would need colour only if the original display was not available. Lastly, none of the participants commented on the Braille as they were not Braille readers.

7. Conclusion and future work

This paper presented the development of a tactile relief and context-aware mobile application to support visually impaired people in experiencing an environmental display of the Booth Museum. The preliminary results suggest that handling opportunities are important, nonetheless clear and direct guidance is of great importance especially for users of an older age. Further collection of data is being undertaken, especially from congenitally blind users and younger visually impaired users, to illuminate the questions around the properties of the relief and form an accurate evaluation of the overall proposed application. Future work within the wider research context will deploy and evaluate other fabricated objects and experiences with different "target" audiences.

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