TOOTEKO: A CASE STUDY OF AUGMENTED REALITY FOR AN ACCESSIBLE CULTURAL HERITAGE. DIGITIZATION, 3D PRINTING AND SENSORS FOR AN AUDIO-TACTILE EXPERIENCE

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ABSTRACT:

Tooteko is a smart ring that allows to navigate any 3D surface with your finger tips and get in return an audio content that is relevant in relation to the part of the surface you are touching in that moment.

Tooteko can be applied to any tactile surface, object or sheet. However, in a more specific domain, it wants to make traditional art venues accessible to the blind, while providing support to the reading of the work for all through the recovery of the tactile dimension in order to facilitate the experience of contact with art that is not only "under glass."

The system is made of three elements: a high-tech ring, a tactile surface tagged with NFC sensors, and an app for tablet or smartphone. The ring detects and reads the NFC tags and, thanks to the Tooteko app, communicates in wireless mode with the smart device. During the tactile navigation of the surface, when the finger reaches a hotspot, the ring identifies the NFC tag and activates, through the app, the audio track that is related to that specific hotspot. Thus a relevant audio content relates to each hotspot.

The production process of the tactile surfaces involves scanning, digitization of data and 3D printing. The first experiment was modelled on the facade of the church of San Michele in Isola, made by Mauro Codussi in the late fifteenth century, and which marks the beginning of the Renaissance in Venice.

Due to the absence of recent documentation on the church, the Correr Museum asked the Laboratorio di Fotogrammetria to provide it with the aim of setting up an exhibition about the order of the Camaldolesi, owners of the San Michele island and church. The Laboratorio has made the survey of the facade through laser scanning and UAV photogrammetry. The point clouds were the starting point for prototypation and 3D printing on different supports.

The idea of the integration between a 3D printed tactile surface and sensors was born as a final thesis project at the Postgraduate Mastercourse in Digital Architecture of the University of Venice (IUAV) in 2012. Now Tooteko is now a start up company based in Venice, Italy.

1. TACTILE EXPLORATION FOR THE VISUALLY IMPAIRED

The loss of sight that characterizes people with visual deficit involves a redistribution of the perception of reality to other senses. In particular, blind people perceive the world mostly from touch and hearing. The tactile exploration of a blind person, regularly called haptic exploration, has some similarities with sight, and Pierre Villey once stated: "La vue est un toucher à longue portée, avec la sensation de couleur en plus ; le toucher est une vue de près avec la couleur en moins, et avec la sensation de rugosité en plus" (Villey, 1954). Tactile perception especially when strengthened from a young age, has the possibility of distinguishing a large number of details even in very small dimensions. The transmission of knowledge for blind people occurs prevalently through touch, through the exploration of tangible objects and the use of alphabetical forms, such as the Braille alphabet.

Simultaneously the perception of the world also occurs through hearing which can give content information (text reading, sonic exploration, etc.) but also spatial exploration. For example the presence of a tray on a table is described in the following way by Augusto Romagnoli: "At the height of my forehead my voice was reflected by a large and non-halogen obstacle, but prominent in the middle. [...] I immediately understood that was the hearing of a circular form, which curve was heard by my hearing thanks to the absence of secondary resonances, which come from well pronounced cuts and from the informal stretching of sound without changes in direction as it happens with the diversity of faces in an angular body." (Romagnoli, 1924). In fact, tactile and hearing perception often help the formulation of mental images of the blind, compensating for sight.

Despite this evidence, the examples of simultaneous union of audio and tactile information are quite rare in communication devices for the visually impaired. In particular, the experiments in synesthetic translation of color through sound operated by the Audiograph (Alty, Rigas, 1998), and the studies on human interfaces based on sounds (Gaver, 1986).

The theme is of high interest because technological help, able to combine touch and hearing to allow a better perception of reality for blind people, can lead the visually impaired to a more complete life and an autonomous exploration of the world.

This need is most relevant in the presence of objects that cannot be touched because of the scale or the value of the piece (such as a church's facade or a painting).

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As it is obvious that fruition of cultural heritage should not be object of discrimination tied to temporary or permanent disabilities, the elimination of barriers for personal disabilities involving some physical operations (removal of stairs, obstacles) could be achieved, while it is much more difficult to reduce the barriers that are mainly perceptive such as those encountered by the people with visual deficiencies.
An ulterior restriction is due to the choice of operating only on works with a tridimensional component (sculptures, objects and architectural works) and not considering two dimensional works of art (drawings, paintings, engravings, etc) which would need a translation from two to three dimension and which goes outside this article's focus.

2. DESCRIPTION OF THE SYSTEM

The system allows, through replicas of works of art made through the use of 3d printing, along with a special ring which is able to read sensors on the replica, to have contextual audio information, relevant to the part of the object that is being touched in a specific moment. In this way an itinerary in museums is offered for visually impaired visitors, but since the possibility of "touching the work of art" is created, the systems becomes useful also for other categories of visitors that favor the tactile dimension, such as children, with the adaptation of content for their needs. The system's goal is to intensify and simplify the relationship with the visitor, always more inclined to using interactive technologies even in the cultural field. Through making available different engineered reproductions of the works for the users, the visitor will benefit from a versatile, multilingual guide instrument, with different levels of depth studying, able to provide for all kinds of visitors, starting from the visually impaired, as an addition to the reading of the work, favoring the experience of a direct contact, even if solely through a 3D reproduction, with the art work.
The system consists therefore in the realization of a technology that transforms mute replicas of a work of art in speaking models, integrating the direct tactile experience with the fruition of localized audio content. This technology, called Tooteko, allows touching a smaller scale model of a museum's work of art, feeling the materials, distinguishing the details with fingertips and listening at the same time, during the tactile recognition, the connected audio illustrations through headphones.
Tooteko puts together touch and hearing in such a way that both hands can explore the object at the same time, while the related audio content is being received by the person that is exploring the surface. A unique object such as a smartphone may detect NFC sensors and give an audio content in return, but the two things cannot happen at the same time while allowing the use of both hands on the surface. Whereas the ring keeps the hand movement free and communicates in Bluetooth mode with a smartphone, a tablet, a pc, an IWB, etcetera.

The system needs some fundamental components such as: the work of art replica to be explored with touch, special NFC sensors that can be inserted inside the object or directly on the surface, an NFC reader able to decode the touched data, and finally a personal audio reproduction system (headphones) that can stream the audio associated with the touched sensor.

Since the audio content is hosted on a cloud, Tooteko offers the opportunity to access content in more languages, to access content tailored for different users, to access music, sounds, or anything that runs on the Internet.

Tooteko technology offers integration between audio and touch, not available elsewhere, thus providing accessibility to audio information by touching any surface that has previously been tagged. Tooteko is a low cost technology that can apply to any three-dimensional surface and make it smart.

The system is made of three elements: a high-tech ring, a tactile surface tagged with NFC sensors, and an app for tablet or smartphone.

Figure 1. System parts

The ring detects and reads the NFC tags and, thanks to the Tooteko app, communicates in wireless mode with the smart device. During the tactile navigation of the surface, when the finger reaches a hotspot, the ring identifies the NFC tag and activates, through the app, the audio track that is related to that specific hotspot. Thus a relevant audio content relates to each hotspot. The production process of the tactile surfaces involves scanning, digitization of data and 3D printing.

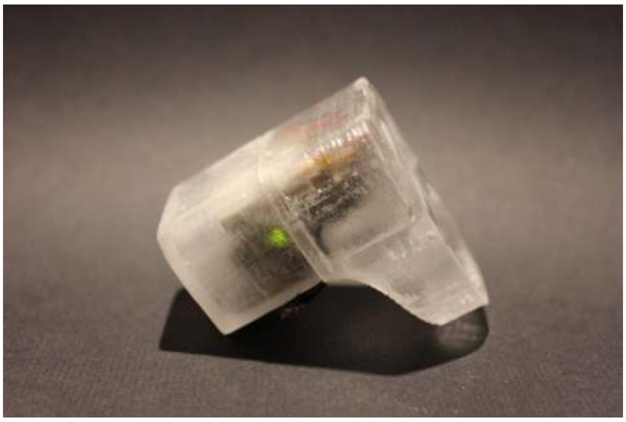

Figure 2. Ring prototype

3. DATA ACQUISITION

3.1 The case study

Tooteko first applied to the model of the facade of the church of S. Michele in Isola by Codussi, which represents the beginning of the Venetian Renaissance. The model is the result of an integrated detection achieved by the Laboratory of Photogrammetry at the Iuav University of Venice (Balletti et al, 2012).

A facade's survey is a traditional operation in architecture, a field of application for new technologies and instruments as well as an opportunity to verify consolidated methodologies. The creation of 3D models requires a powerful methodology able to capture and digitally model the fine geometric details of such architecture (Remondino, 2011). The point cloud, a very useful instrument in the realization of vectorial drawings and of tridimensional models, in this case derives from both the laser scanning of the application of multi-image photogrammetry and the images obtained through an Unmanned Aerial Vehicle (UAV).

3.2 The reality based survey

The first part of the survey was achieved with a laser scanner at phase difference. The achievement of the facade was reached with the Faro Focus 3D instrument, well known on the market (Balletti C. et al, 2013, Giannattasio et al., 2013) and characterized by a high speed of acquisition (up to 900.000points/sec) and high precision (± 2 mm between 10 and 25 m).

The scan acquisition scheme recalls the monoscopic convergent photogrammetry scheme that requires a central station, one from the right and one from the left to minimize shadow zones (at least those with horizontal trend).

It was chosen to make the scans at highest resolution to obtain a very dense point cloud and therefore permit the extraction of a high quality pseudo-orthophoto. Four scans were taken from the external space in order to contextualize the prospect of the church. Furthermore, four scans were taken from inside the church to investigate on the relationship between the facade and the inside of the church.

In this context, the instrument is particularly effective as it allows to achieve the whole spherical cap, with a horizontal coverage of 360 degrees and a vertical coverage of 270 degrees.

Figure 3 The laser scanning point cloud of the facade of San Michele in Isola

Figure 4. DSM of the facade of the church with "shadow" zone due to entablatures

The sum of the four scans has allowed to have, for the sole facade, a cloud of around 45 million points with a step in the lower part lower than around 1 mm and in the upper part around 5 mm.

The registration of the point clouds was achieved topographically. The targets, recognized semi automatically by the dedicated software Faro Scene, were detected with a total station to guarantee the verticality of the local reference system and for the management of all the scans – both of the inside and the outside – in one unique reference system. The georeferencing was also tuned up by adding some geometrical links. For example, some planes with horizontal and vertical arrangement were identified and used as tie-plane between the different scans.

First result of the survey was therefore the point cloud (fig. 3-4) obtained through laser scanner, in which are obvious the deficiencies determined by the facade's overhangs. In the zones underlying the entablatures you can in fact see a section in which no data was obtained (around 0.4 was the gap of data due to the first entablature and up to 1.2 on the second).

In the case of San Michele in Isola this effect is particularly evident since the church's parvis has a contained depth (round 8 meters) and it is therefore not possible to carry out the achievement of data from larger distances. The characteristics of the facade make these deficiencies particularly serious. There is no way to obtain a complete representation of the shells on top of the lateral aisles.

As a remedy for the deficiencies shown by the point clouds, generally, there is an attempt to utilize mechanical vehicles to raise the point of view (forklifts or mobile platforms) and carry out the photogrammetric photos or other laser scans. In particular environments like in the Venetian one, using such systems becomes complex both for the movement of the vehicles, and because the bearing capacity of the walking surface is quite limited. This last aspect in fact requires the use of lighter systems that do not allow reaching great heights and that are relatively unstable.

For all these reasons, for this detection, the final choice was to use UAV systems (Unmanned Aerial Vehicles) that in the last few years have had a remarkable development in terms of maneuverability and the possibility of stationary flight in accordance with electronic development (Nex et al, 2014).

Figure 5. the Align Trex helicopter, equipped with GPS and the Sony Nex camera and its ground control

These systems are characterized by their transportable weight limit, but digital cameras for high angle pictures can be mounted easily.

In a second phase the acquisition was carried out through high angle pictures achieved with low cost and amateur equipment: the Align Trex helicopter (fig. 5), equipped with GPS and the Sony Nex camera with a 24mm lens. The aircraft was flown from the ground following the trajectories that could allow the achievement of the aerial stips suitable for restitution with a multi-image system. The path and the camera's photos were followed and recorded through a pc.

In this case, having to fly so close to the building, manual control of the helicopter was preferred over the autopilot in order to avoid trajectory errors that could be caused by potential signal losses, which could damage the facade. For the photos, working without a pre-set shot time was preferred, observing the angle from the ground and shooting with the remote to have better control of the coverage and the framed subject. The operations, conducted throughout three flying sessions of around 7 minutes each, were conducted within the period of the morning, clearly much less time than what any other system would take.

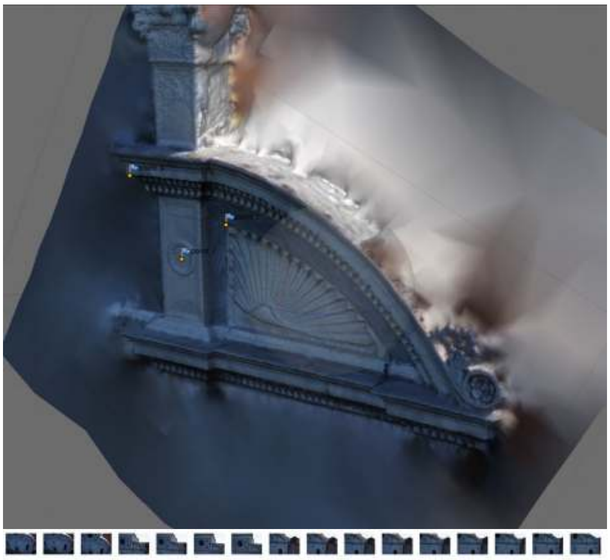

Figure 6. The photogrammetric model of the upper decoration of the facade in Photoscan

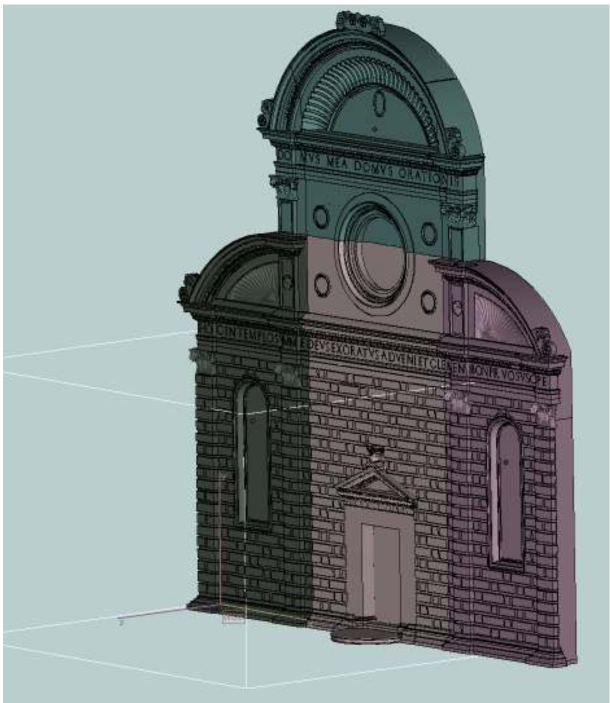

Figure 7. The STL model divided into 4 parts

At the end of the process, the over 500 images taken were used to add to the data already obtained. Among the different possibilities, it was chosen to use a multi-image photogrammetry to obtain a point cloud that would go to complement the already existent one (lo Brutto et al., 2012).

The frames were elaborated with the Photoscan software by Agisoft to obtain a tridimensional model of the facade's upper side, in particular of the zone that was presenting a gap in the model obtained by the laser scanners. The software uses tough algorithms that allow the orientation of the images even though obtained with a configuration that did not correspond with the photogrammetric principles.

For the modelling of the facade, various models were created to complete the various deficiencies. For example, in the model of the part just above the architraves that also includes the shells, 21 images were used. The point model obtained (fig. 6) was scaled not by using a clear measure, but going back to the points achieved with the laser scanner. In this way, the point cloud obtained through photogrammetry was not only scaled but also georeferenced in respect to the laser data. The alignment of the two datasets was occurred with 3mm error.

Other models were made for the facade's details such as the rosettes on top of the curved gables and the statue. At the end of the surveying campaign a unique point cloud was produced, in which the laser scanner data was integrated with the data obtained through the dense stereo matching.

3.3 The 3d printing

In order to proceed with the solid printing it was necessary to build a tridimensional model. The abundance of points and the integration of the extracted photogrammetrical data allowed the realization of a mesh model for the whole facade. Therefore inevitable small deficiencies and zones with higher noise were still compatible with the scale chosen for printing.

Figure 8. The final resin model

The process for the realization of the model is the one already well known in literature.
After the external processing of the data to get all the clouds (laser scanner and photogrammetrical ones) in the same reference system, every scan was decimated and cleaned void of outliers and noise until achieving a one unique point cloud.
The triangulation, the closing of the holes and the essential cleaning operations of the mesh allowed reaching the printing-ready model.
The solid print is made with the Ultra 2 printer by Envisiontech, based on the technology of image projection on curing resins. The model is divided into very thin slices (50 micron width) that are then printed individually and end up composing the whole model. Since the Ultra 2 has a reduced print dimension and the chosen scale was 1:50, the model had to be printed into 4 parts (fig.7), later glued together thanks to resin (fig.8).

3.4 Nfc tags

After having created an exact replica of the architecture as previously described, it is necessary to insert inside the object a series of hotspots that, when touched, stream the unique identifying code that characterizes them. NFC (Near Field Communication) technology is characterized by a passive component (tag) and an active component (sensor). Through the proximity of these two elements (normally less than 3cm) an electromagnetic field is created by the two loop antennas. This electromagnetic field is able to provide enough energy for the tag (passive component) to wake up and read and write the data inside the internal chip. NFC operates at 13.56 MHz on ISO/IEC 18000-3 air interface and at rates ranging from 106 kbit/s to 424 kbit/s.
NFC tags (passive components) are then inserted inside the model, even though an irreversible operation, since they do not require maintenance or batteries.
The NFC tag decoding happens through an extremely compact module based on a Philips PN532 processor for contactless communication at 13.56MHZ. The PN532 supports different operating modes and the system uses a Reader/writer mode supporting ISO 14443 / MIFARE.

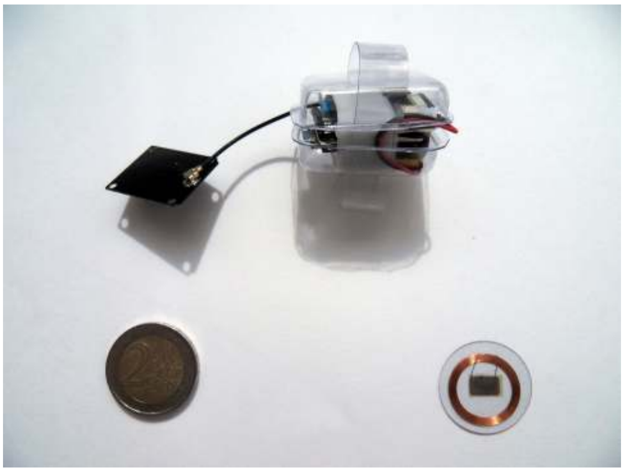

Figure 9. NFC tag and sensor

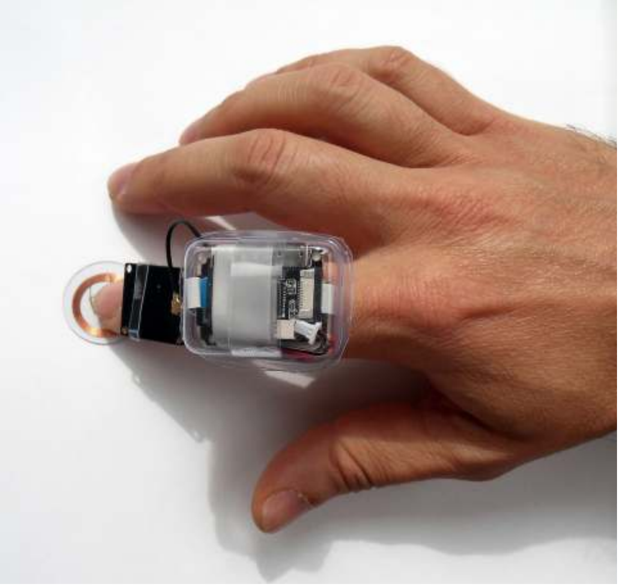

Figure 10. Deconding NFC tags

The PN532's internal transmitter part is able to drive a reader/writer antenna designed to communicate with ISO14443A /MIFARE, guaranteeing a reliable demodulation and decoding circuitry for signals.

3.5 Processing and sending collected data

When the PN532 reader collects an external tag compatible with ISO 14443A it begins the decoding through the NFC antenna of the tag's content. Inside the tag is inserted a unique ID string that contains the following data: museum ID/work of art ID/part of the artwork touched ID, with an XXX;YYY;ZZZ format.
This information is elaborated by an Atmega32u4 processor by Atmel Corporation. The Atmega32u4 is a processor of small dimension that works at 8 bit with 16 MHz, featuring 32KB self-programming flash program memory.


Figure 11. Hotspots

The string that results from the reading of the tag is then sent via Bluetooth to the device that expects the reception (smartphone, tablet or audio guide). To avoid interference with other rings present inside in the museum, another string containing the ring's unique ID is sent simultaneously. This way the system expecting the reception can filter the arriving data and allow a virtual pairing, without access control, which makes the relation between the ring and the touched tag unique.

3.6 The App

The audio reproduction system is made up by a common smartphone or tablet, equipped with a specific app that has the task of receiving the Bluetooth LE signal, filtering the information, entering the database (internal or remote depending on the situation) and streaming the audio relative to the received string. In substance, the portable device bypasses the compatibility problem of NFC decoding (which is not a standard since most portable devices on the market are still not equipped with an NFC reader or still hasn't added it as a standard, as is the case for Apple products) giving the electronic ring the task of working as a bridge between NFC and portable devices through Bluetooth transmission, which is on the contrary a consolidated standard.
The string transmitted by the ring therefore contains the data relative to the user's identification, to the museum that owns the work of art, to the artwork and to the specific hotspot.
This string activates a remote audio file (which can be provided in audio streaming in the case of personal devices) or locally (in case of an audio guide) that takes into consideration the user's language and his target demographic (adolescent, expert visitor, common visitor or other) to allow a selection of information based on the user's needs.

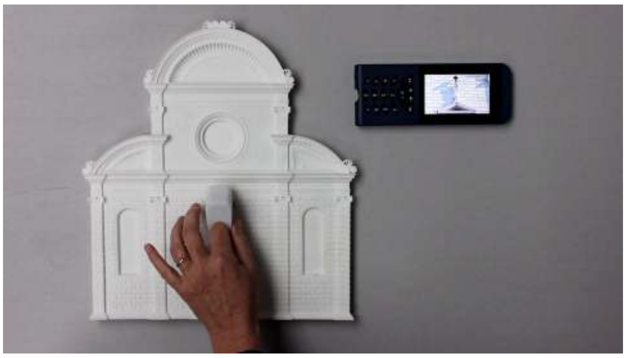
Figure 12. Data Transmission

4.1 Conclusion

3d printing is experiencing a quick evolution, and allows, through digital data collection and the translation to a point cloud and successfully a mesh, the reproduction of works of art and architectural works in tangible objects at a low price. The following engineering of these models can allow the creation of objects that can be touched and will then stream multimedial information (audio and video) relative to specific points and guarantee an experience of augmented reality.

In a more specific domain, Tooteko wants to make traditional art venues accessible to the blind, while providing support to the reading of the work for all through the recovery of the tactile dimension in order to facilitate the experience of contact with art that is not only "under glass."
Tooteko offers the enjoyment of the work of art in its context, and not in a museum of replicas for the blind, and at the same time it offers the possibility for other categories that favor the tactile dimension, such as children, to approach the work of art, adapting the content to their needs.

This augmented reality can be of particular effectiveness to also permit the fruition from objects of cultural heritage to people who suffer from sensorial deficiencies such as the visually or hearing impaired, allowing a sensible reduction of the barriers.

Figure 13. Accessible cultural heritage).

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