Title:
Raising Awareness about the Consequences of Human Activities on Natural Environments through a Multisensory AR Experience

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Introduction:
Museums have been subjected to important changes in the approach they use to involve visitors, also by using digital technologies. So, they are implementing a digital revolution with the aim to change the way people relate to and visit the museums. This is even more true when we refer to museums as places of culture and to the activities of museums in relation to their pedagogical role, referring not only to exhibitions of pieces of art and artistic experiences, but also to exhibitions concerning current topics in cultural and social affairs, such as technological, environmental, sociological issues. Among the other trends, storytelling and interactive exhibitions are two of the most used approaches used to make the exhibition more and more interesting for the users who visit it [12]. So, from the traditional concept in which museums and exhibitions were “show-and-tell” spaces [6], in this new scenario they are becoming spaces where it is more and more possible interacting with pieces of arts.

There are several approaches used to make museum exhibitions interactive. One of the most used and easy-to-implement approach used to carry out this process of innovation is the digital interaction. Specifically, Virtual Reality (VR) and Augmented Reality (AR) methods can be effectively used in the context of a museum exhibition to support both storytelling and interaction [4]. In particular, by means of AR applications, visitors can enjoy immersive experiences in which the content, the history and the meaning of pieces of art, objects, situations are digitally added onto the real artifacts. Indeed, AR is nowadays more and more used for museum exhibition, to add virtual contents to the real ones and "increase" the reality.

Nowadays interactive exhibitions in museums are becoming broadly common, thanks to their flexibility of application and effectiveness in engaging visitors in the experience. So, visitors are becoming active “consumers”, and are able to define their own journey and experience at the museum. One emblematic example is interactive exhibitions for younger audiences, and specifically for children. In this case, museums frequently allow young visitors to “play” with exhibits, in order to make learning new knowledge an interesting and pleasant experience [2].

Concerning the use of VR and AR applications, people are becoming more and more familiar with hybrid realities that make it easier to use these technologies. Some museums present digital labels or touchscreen tables with texts and information as “side elements” of their exhibitions. Other museums

effectively rely on technological devices and applications that represent the only way users can interact with pieces of art. At the Casa Batlló in Barcelona, visits are carried out by using an AR guide, which provides a dynamic and semi-immersive experience [7]. Finally, in many other cases, museums develop VR and AR experiences of some special exhibitions.

The primary objective of the use of these technologies is to make the visit of museums much more engaging, immersive, and suitable for different types of visitors. In particular, the common idea is to "extend" the target audience also to those who are not experts in the topics described in the exhibition who, through the new co-communication methods, can better understand concepts often considered as very complex. In this sense, in fact, the possibility of viewing the history of the objects and their meaning instead of reading or listening to the explanation, or rather of looking at images / animations instead of reading texts, reduces the need to have experienced and knowledgeable users, and increases the possibilities of learning and remembering information. In the "non-expert users" category, it is also possible to include children, who are often fascinated by science, nature and art, but are hardly interested in static representations that are very difficult to understand.

New exhibitions aspire to raise acknowledgement and curiosity among the visitors, especially children and teenagers. In fact, interactive exhibitions are becoming more and more appreciated and effective, involving people through different senses and calling them to action. They need to perform an action in order to see a corresponding reaction inside the environment or in the object shown. Moreover, as suggested by the psychological embodied cognition theories, better learning is achieved when the body is involved in the process, as compared to when the experience consists in a mere observation [9]. This approach can generate a higher awareness about the problem and lays the foundations for behavioral changes in daily life.

Moreover, nowadays the design of the user experience of artistic tours in museums and exhibitions is one of the most important aspects. The user experience is strictly linked to how the user interacts with the artifacts at physical, perceptual, emotional and cognitive levels. This means that it includes also the design of multisensory experiences that satisfy sight, touch, hearing and smell senses in order to improve the exhibition understanding and the user's engagement [3]. From a neurological point of view, this is related to the fact that typically the human brain integrates information from different sensory modalities [11] and then produces a univocal final experience of the external world. In particular, the sense of smell plays an important role, since it recalls memories and deep emotions and can help the customer to feel involved into and emotionally linked with objects, people, situations, etc.

In the last years, several studies have focused on the integration of odors in VR and AR environments by developing devices named Olfactory Displays for different applications [1]. Even if some technical issues still remain unsolved, some companies have developed and launched on the market olfactory displays for VR/AR applications. For example, the Vaqso device (https://vaqso.com/), the Olorama scents generator (https://www.olorama.com/), and the Feelreal device (https://feelreal.com/). However, the use of sense of smell is underexplored, especially when its possible application and impact can be quite effective. Indeed, the sense of smell is one of the more primordial sense in humans, and it is linked to more basic emotions in comparison to the other senses [8].

So, the purpose of the research work presented in this paper was to design and develop an interactive multisensory AR application (based on sight, hearing, and smell senses), which can be used for improving the user' experiences of exhibitions and the comprehension of their contents. Specifically, the paper presents a case study in which a multisensory AR exhibition concerning negative effects of human activities on natural environments has been designed and developed. Then, preliminary testing sessions with users concerning the users' involvement, comprehension and overall experience have been carried out, and preliminary analyses of the collected data will be presented.

Main idea

The *Changing Earth* experience is a multisensory AR experience that involves sight, hearing and smell senses and aims at improving the users' engagement and understanding of the negative effects that human activities have on different natural environments. Specifically, Changing Earth experience aims to augment the experience of a time journey throughout different natural environments affected by human activities. The Changing Earth experience consists of an AR application integrated with audio and olfactory stimuli for allowing visitors of the exhibition to be more immersed in the experience.

So, the *Changing Earth* experience has the aim to give users a new and different way of comprehension of the pollution problem, and the role of individuals in facing the problem. Using AR technology and olfactory devices to solicit visual and olfactory stimuli actively engages the user and lays the foundations to create an exciting and longer lasting memory in the users' mind. Thanks to the correlation between the AR application and the olfactory stimuli, when users perceive the smells, their feelings and emotions are amplified. In fact, smells let them remember more the different feelings experienced when enjoying the experience.

The AR multisensory experience is based on a deep analysis of the pollution problem, the correlation with human activities and the effects on two different natural environments: the Amazon rainforest and the Great Barrier Reef. These two ecosystems have been chosen since they well represent the global environmental crisis we are facing in these years. Indeed, as reported in [10], the main activities responsible for the deforestation are small farmers, cattle ranchers, miners and loggers, and the environment and economy of the rainforest are at a critical point since years. Moreover, a research based on the world's most extensive time-series data on reef condition shows how the world's coral reefs are being degraded through time due to direct human activities, climate change and related climatic conditions such as tropical cyclones [5].

So, the *Changing Earth* experience has been designed to illustrate human activities effects on these two natural environments through the visualization of changes in a period of about 50 years. In particular, for the rainforest environment, the application shows how deforestation began from small farmers that cleared huge land areas to guarantee continuous sources of income. Then the impact of miners, that destroyed and changed rivers' paths for gold extraction, also polluting water with mercury in the process of extraction, is shown. Finally, the application shows the most recent activities of intensive breeding and logging, due to the trending markets of meat and wood.

For the Great Barrier Reef environment, we wanted to make people aware of the acidification of water caused by the increasing pollution due to industrial human activity, and the rise of the temperatures of water. The set of activities described is related to climate change that eventually led to the coral reef bleaching. The application also shows the problem of the lowering salinity of water due to the increase of melting of glaciers around the world and the more recent problem of plastic pollution.

For what concerns the architecture of the AR multisensory *Changing Earth* experience, it is structured in two main groups of components, as shown in Fig. 1.

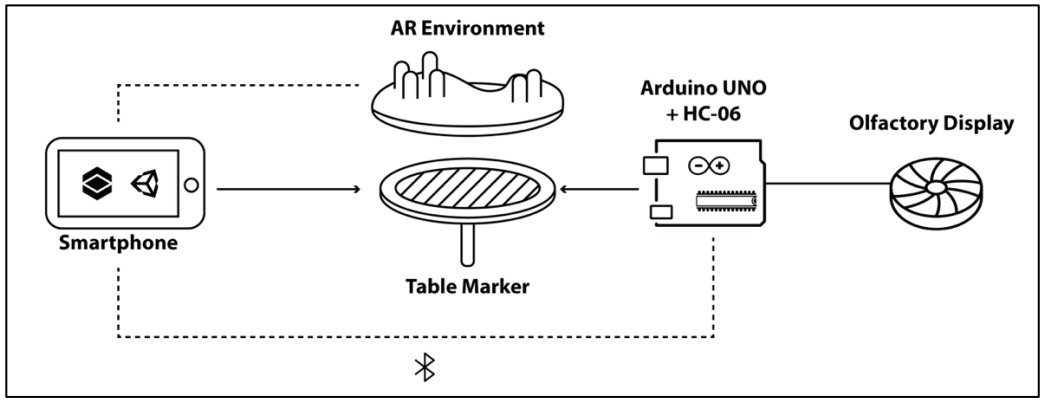

Fig. 1: The architecture of *Changing Earth* experience.

The first main group of components consists of the AR application, displayed on tablets or smartphones, which allows visualizing the AR environments. In each of these AR environments, a natural environment and the changes to which it has been subjected in every decade are shown. At first opening, the application provides a tutorial and explains to the user the interaction modalities. The AR application is triggered by markers, representing the natural environments, printed on round tables. So, visitors

walk around each round table pointing with their smartphone the marker for experiencing the whole-time journey. For each position of visitors around the table and the related decade, a different content is visualised. For example, in the rainforest, the first decade is the 60s, when the rainforest was pristine and lush, florid of trees and brushes; by moving anti-clockwise around the table, the environment changes to the 70s when visitors can observe the first signs of deforestation and the first cultivated fields.

Fig. 2: The rainforest environment as visualized at the beginning of the experience (the 60s) and after the first step (the 70s).

A recorded voice accompanies the changes of the natural environments, with the purpose of:

- explaining how to trigger the AR environment for the first time;
- assisting visitors if they lose the tracking or are moving in the wrong direction;
- narrating the changes that the visitor can see;
- giving more information about the content of the natural environments.

If visitors want to get more information about what they are seeing, they can press a dedicated button and look at some archive photographs that better describe the pollution problems.

At the end of the journey of each natural environment, the AR application visualizes a menu with three hypothetical future scenarios among which visitors can choose one option. By clicking on one of them, visitors can see a video that envisions the content of the scenario. For example, in the case of the rainforest, visitors are asked to discover what will happen if we lost the rainforest, if everyone would become vegan or if we planted millions of trees. While the purpose of the first part of the AR application is to improve visitors' knowledge and awareness of the negative effects that human activities have on different natural environments, these scenarios aim to suggest and arouse changes in visitors' behaviors.

The Unity3D (https://unity.com/) and the Vuforia (https://developer.vuforia.com/) software tools have been used to develop the AR application. Specifically, the virtual representations of the natural environments have been developed in Unity3D, and the Vuforia software has been used for the development of the AR visualisation of the contents. Concerning the possibility to use a single marker for different decades, it has been developed by using a script that keeps track of the angle between the marker and the device running the application, so that the scene in augmented reality can change accordingly to that angle.

The second main group of components consists of the table to place the marker and the four olfactory displays to delivery odors related to the AR experience. The diameter of the table is 1.4 meters, and the olfactory displays are placed at 0, 90, 180 and 270 degrees. Each olfactory display consists of a small fan placed under the table, with a cotton pad soaked with a specific odor in liquid form. The olfactory displays run one at a time and are activated when the visitor starts experiencing a specific decade.

The odors to be released have been carefully selected to create a link with the AR environment and to enhance the comprehension of its meaning. Specifically, for the rainforest, we opted for some green and floral scents to be spread during the first decades, while some burning and smoky odors are increasingly released together with the deforestation.

Similarly, for the Great Barrier Reef environment, we opted for some positive odors of sea breeze and sea flowers at the beginning, while odors of dead fish and pollution will appear going on in the experience. The olfactory displays are connected to an Arduino Uno board, which is placed below the table and communicates to the AR application through a Bluetooth connection for activating the olfactory displays (see Fig. 1).

Conclusions

The research work presented in this paper focuses on the possibility to improve the user experience of educational exhibitions through a multisensory AR application (based on sight, hearing and smell).

Specifically, the Pollution experience has been designed and developed with the aim of improving the user's engagement and understanding of the content, as well as to generate awareness about the ecological problem. Particular attention has been devoted to the integration of olfactory stimuli and their combination with the other senses. Indeed, the olfactory stimuli have been designed with the purpose of involving the user both at a subconscious and conscious level, in order to elicit emotional responses and facilitate the creation of long-lasting memories. So, the preliminary testing sessions carried out with users concerned the users' involvement, comprehension and evaluation of the overall experience. The usability of the application was also tested. In the final paper a preliminary analysis of the collected data will be presented.

It is worth saying that both the use of Augmented Reality and the multisensory approach are still rarely used for interactive exhibitions. On the opposite, these technologies can be effectively used to create an emotional link between the readers and objects and facts, to improve the users' experience and knowledge. So, in an envisaged scenario, multisensory AR applications similar to those presented can be developed and implemented in a wide range of exhibitions concerning scientific and technological topics, as well as cultural heritage and historical contents.

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