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Raising Awareness about the Consequences of Human Activities on Natural Environments through Multisensory Augmented Reality: Amazon Rainforest and Coral Reef Interactive Experiences

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Abstract. Cultural and educational institutions have been subjected to important changes in the approach they use to involve the public in the last years. For example, museums are more and more playing a pedagogical role, referring not only to exhibitions of pieces of art, but also to exhibitions concerning current topics in cultural and social affairs. Storytelling and interaction are two of the most popular methods used to make exhibitions more interesting for the visitors, and many works have demonstrated that Virtual Reality and Augmented Reality technologies can be effectively used to support these approaches in the context of museum exhibitions. This paper presents a research work aimed to design and develop an interactive multisensory AR application (based on sight, hearing, and olfaction senses), which can be used for improving the users' engagement in exhibitions and generate awareness about the dramatic outcomes of pollution on the environment. Specifically, the paper describes a case study of multisensory Augmented Reality interactive experiences concerning the negative effects of human activities on natural environments.

Keywords: Augmented Reality, Multisensory Perception, User Experience
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1 INTRODUCTION

Cultural and educational institutions have been subjected to important changes in the approach they use to involve the public, also by using digital technologies. Therefore, we witness a digital revolution aiming at changing the way people relate to and visit educational spaces. Boundaries between cultural activities and places are starting to be progressively reduced, also with the aid of technology. For example, museums are now, more than ever before, playing a 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, and sociological issues. On the other hand, school and universities are also starting to expose art pieces and offer hedonic as well as educational experiences in conjunction with art galleries and museums. Technology is certainly offering great means to further facilitate this educational interaction.

Among the other trends, storytelling and interactive exhibitions are two of the most popular approaches used to make the exhibition more and more interesting for the visitors [38]. Therefore, from the traditional concept for which museums and exhibitions were “show-and-tell” spaces [10], in this new scenario, they are becoming spaces where the interaction with pieces of art, objects, and human artifacts is increasingly possible with important educational purposes.

There are several approaches that have been used to make museum exhibitions interactive. One of the most used and easy-to-implement consists of realizing digital interactions. Independently of the technology used, the exhibits tend to be dynamic and interactive rather than static. Obviously, the technological choice must clearly be motivated by an enrichment of the experience, and not only by placing itself in a technology-push perspective, where available technologies are simply adopted even if not functional to the purpose.

Digital technology often seems to blur the line between education and entertainment in the museum galleries [25]. Following this path, a neologism *edutainment* has been coined (Bob Heyman, documentary maker at National Geographic), which is a synthesis between education and entertainment. The entertainment should be used in response to the specific needs of the target and should meet the educational proposal of the museum.

Many works have demonstrated that Virtual Reality (VR) and Augmented Reality (AR) technologies can be effectively used in the context of museum exhibitions 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, and situations are digitally added onto the real artifacts. Indeed, AR is nowadays more and more used for museum exhibitions, for adding virtual contents to the real ones, to "increase" the reality of the exhibit and improve learning. It is worth noting here that, from a pedagogical and neurocognitive point of view, a more direct interaction with a given topic has been shown to facilitate people’s learning process.

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 olfaction senses), which can be used for improving the users' enjoyment of exhibitions and generate awareness about the dramatic outcomes of pollution on the environment. That is, sensory and hedonic contents are embedded into a technologically advanced solution, that might have an important educational value. Specifically, the paper presents a case study of a multisensory AR exhibition concerning the negative effects of human activities on natural environments. The paper presents the design and development of the AR exhibition, and preliminary comments from users about their enjoyment of the overall experience.

2 LITERATURE REVIEW

Nowadays interactive exhibitions in museums are becoming broadly common, thanks to their flexibility 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 them acquire new knowledge, and enjoy pleasant experiences [7].

New exhibitions aim 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. Typically, in these cases, the users are prompted to perform an action in order to see the resulting effects on the environment or on the physical or digital artifact itself. This interactive approach is particularly effective for two reasons. First, it engages the users' body, an aspect which is considered fundamental for improving our learning process according to the well-known psychological theory of embodied cognition. This theory suggests that cognition is heavily grounded on sensory-motor experiences, meaning that better learning is achieved when the body is involved in the process, as compared to when the experience consists in a mere observation or listening [31]. Second, being actively engaged in the educational process, instead of being the passive recipients of notions, allows the users to catch the deep meaning of the subject-to-be-learnt, to develop logical and semantic links with related topics, and to elaborate a personal and critic vision. Technology can provide a huge boost to this process, enabling the user to experience the exhibition in a multimodal way. For instance, the powerful learning effects of presenting a topic through the integration of multisensory contents, as compared to reading paper books, is already quite evident. Schools are in fact implementing new methods to deliver interactive digital lessons able to attract the students' attention and maximizing the probability of storing and retrieving information (a sort of technological application of the so successful Montessori educational principles) [6, 27]. The continuous and fast development of new exciting technologies will certainly continue to offer new opportunities to revolutionize the educational process.

The exploitation of this interactive approach is particularly appropriate to generate a high and deep awareness about problems related to environmental sustainability. It is also worth considering here that this approach is particularly effective in generating durable behavioral changes, especially when the process is supervised over time by means of apps able to monitor the users' behavior and nudge them to start new actions and generate new habits. These steps constitute in fact the foundations for implementing behavioral changes in daily life [33].

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]. The primary objective of the use of this technology is to make the visit to 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, 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 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 (not to mention those who have reading disabilities).

Concerning the use of innovative technologies, exhibitions can assume various forms depending on the applicative scenario and the target end-users. Visitors can use smartphones and tablets throughout the site or access the collection contents online and use online channels before and after the visit, or to enjoy virtual contents with Head Mounted Displays supplied by the museum, or a mix of all these possibilities. Indeed, people are becoming more and more familiar with hybrid realities (Real, Virtual, and Mixed Realities), which are turning increasingly easy to use in public events and for cultural heritage purposes. More specifically, 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.

In particular, by means of AR applications, visitors can enjoy interactive experiences in which information and digital contents related to places, pieces of art, objects and situations are added onto the real artifacts [29] to "increase" the reality. For example, at the Smithsonian National

Museum of Natural History the Augmented Reality “Skin and Bones” application is used to frame skeletons of vertebrate animals in the Bone Hall and visualize how they look when alive [12]. At the Casa Batlló in Barcelona, visits are carried out by using an AR guide, which provides a dynamic and semi-immersive experience [15]. “Story of the Forest” is an immersive permanent AR installation at the National Museum of Singapore that transforms several drawings from the William Farquhar Collection of Natural History Drawings into three-dimensional animations [17].

In many other cases, museums develop VR and AR experiences for some special exhibitions. Among the others, in 2015, the British Museum’s Samsung Digital Discovery Centre (SDDC) held a Virtual Reality Weekend in the Museum’s Great Court, offering the visitors the possibility to enjoy VR environments through immersive and non-immersive devices [34]. In 2017, the Natural History Museum in London featured an interactive VR experience in which visitors were able to virtually handle fossils and other pieces from the Museum's collection in a one-on-one interactive experience [18]. Also, at the National Museum of Natural History in Paris it is possible to enjoy the *Virtual Arctic Expedition experience* in the *Cabinet of Virtual Reality*. Here, up to 8 users are immersed together in the Arctic seabed wearing a scuba diving suit and can meet whales, belugas, orcas and giant jellyfishes [16].

Innovative technology is used both in cases of art exhibitions and scientific exhibitions, and in many cases the use of this technology allows extending the users’ experience outside the museums’ physical spaces. As an example, it is possible to live a museum experience at home with the use of augmented reality directly, as in the case of "Civilisations AR" designed by Media Applications Technologies for BBC [14]. The application allows users to see in AR the main artifacts located in UK museums, rendered with a good degree of photorealism and in full scale.

Moreover, some exhibitions are of particular interest for this research work as they focused on the topic of environmental sustainability and climate change. For instance, the “Human Footprint” exhibition, curated by eoVision and presented at the Natural History Museum in Salzburg in 2013, was a collection of 50 satellite images depicting mankind’s visible influence on the appearance of planet Earth. EoVision, in collaboration with Wikitude, also developed a book related to the exhibition named “OneEarth” in which a collection of 119 satellite images was presented and used to visualize the status of the Earth’s environment [19]. Also, these images were used as markers for an AR application, to be installed on personal devices, to visualize additional information, different views and 3D models related to each environment (see Figure 1).

Figure 1: eoVision AR application showing the status of the Earth’s environment.

Similarly, NASA created different applications based on pictures from NASA's satellites and missions. Among them, a virtual gallery named “Images of Change” [11] features images of different locations on planet Earth, showing changes over time periods (see Figure 2). Some of these effects are related to climate change, some document the effects of urbanization, or the ravage of natural hazards such as fires and floods. The aim of these applications is to make people think about the impact of humans on Earth.

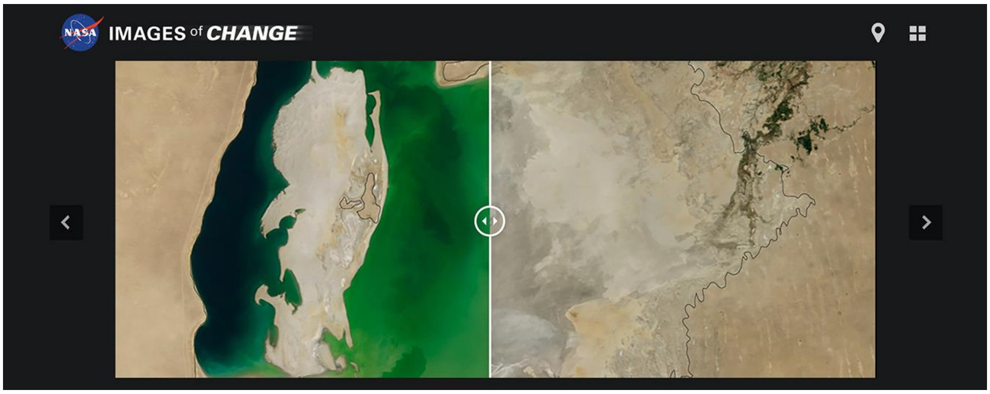

Figure 2: NASA application consisting of a virtual gallery of locations on planet Earth [11].

Furthermore, "After Ice" is a mobile application, developed by Ghostweel, that uses Augmented Reality to simulate the effects of climate change around the world [13]. The app works by simulating your location in various future scenarios of global ice melt and sea level rise (see Figure 3), basing on data coming from NASA projections. The aim is to visualize long-term processes which are difficult to imagine, making people aware of what could happen in the future if we do not change our habits.

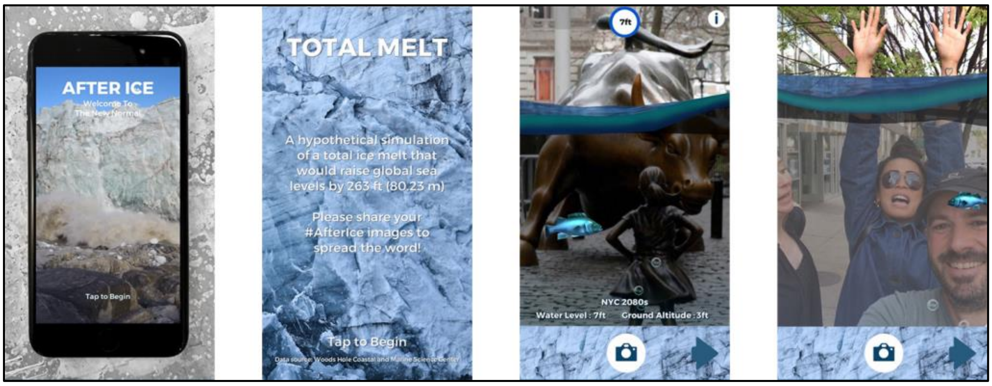

Figure 3: Ghostweel AR application simulating the effects of climate change around the world [14].

Nowadays, impressive exhibitions are often the result of a careful design process of the user experience (UX) aspects, with physical or digital artifacts requiring a high level of interaction being liked the most. In fact, including the users as active participants to the exhibition, makes them feel more excited and entertained. Another crucial aspect of offering a successful exhibition is represented by the communication through the various sensory channels. In fact, exhibitions that offer multisensory experiences are known to increase the understanding of the exhibition meanings, as well as the users' engagement [8]. When vision, touch, hearing and smell senses are simultaneously stimulated, the appreciation of the artifacts is much more intense and resembles natural situations, as it happens in daily life. From a neurological point of view, these effects are mediated by the integration of the information coming from the different sensory modalities, which results in a unified final experience of the external world [36].

Among the different sensory modalities just mentioned, smell has been for a long time underestimated, both in the scientific and artistic fields, especially if compared to vision and hearing (and somehow also to touch; [7, 37]). Nevertheless, the sense of smell is one of the most primordial senses in humans [22] and boasts a direct and immediate link to the oldest brain areas, namely the limbic lobe, that is involved in the retrieval of memories and emotional processing. For these reasons, in the last decades, the role of smell has been acknowledged in many different domains and designers have begun to exploit it to generate emotional links between users and products [1], people or situations [3]. In the last years, several studies have focused on the integration of odors in VR and AR environments by developing devices named Olfactory Displays, which have been used for different applications [37]. Various technologies are used to develop an olfactory display. These are categorized by scent generation methods and scent delivery methods [28]. Several research works concerning olfactory displays have been presented in literature [2, 9, 22, 24, 30, 35]. 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/). Also, Maggioni et al. [28] presented a design toolkit for smell (i.e., OWidgets) that consists of a graphical user interface and the underlying software framework. The framework uses a Mapper and a Scheduler facilitating the device replication of olfactory experiences. However, the use of the sense of smell is underexplored, especially for what concerns its possible application and impact, which can be quite effective.

3 RESEARCH SCOPE

On the basis of the literature review, the authors identified the opportunity to develop multisensory interactive exhibitions to generate awareness about the outcomes of pollution on the environment and make people reason about how they can directly contribute to limit the extension of this problem.

In particular, the impact of human activities on the Earth Planet is more and more evident, and several groups of activists, such as the recent *Friday for Future* (https://www.fridaysforfuture.org), are now trying to raise people’ interest on this enormous problem. So, with the aim of increasing the awareness of this issue to people and, more importantly, to children, the authors designed and developed an interactive and engaging exhibition named “Changing Earth”.

The Changing Earth experience is a multisensory AR experience that involves sight, hearing and olfaction, 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 and show how these environments changed during the last 50 years.

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. The experience has the aim to give users a new and different way of comprehension of the pollution problem, and of 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. Moreover, when enjoying the experience, the perception of the odors facilitates the creation of a link between emotion and memory, which will result in an increased probability of leaving a trace in the users’ experience.

Based on a deep analysis of the pollution problem, two different natural environments were selected: 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 [32], 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, research based on the world's most extensive time-series data on reef condition shows how the world of the coral reefs is being degraded through time due to direct human activities, climate change and related climatic conditions such as tropical cyclones [5].

Therefore, the 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. Specifically, for the rainforest, the authors showed how deforestation began from small farmers that cleared huge land areas in order to guarantee continuous sources of income. Then the impact of miners, that destroyed and changed river paths for gold extraction, also polluting water with mercury in the process of extraction. Then the most recent activities of intensive breeding and logging, due to the trending markets of meat and wood were shown.

For the Great Barrier Reef environment (see Figure 4), the authors 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. It is also shown 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.

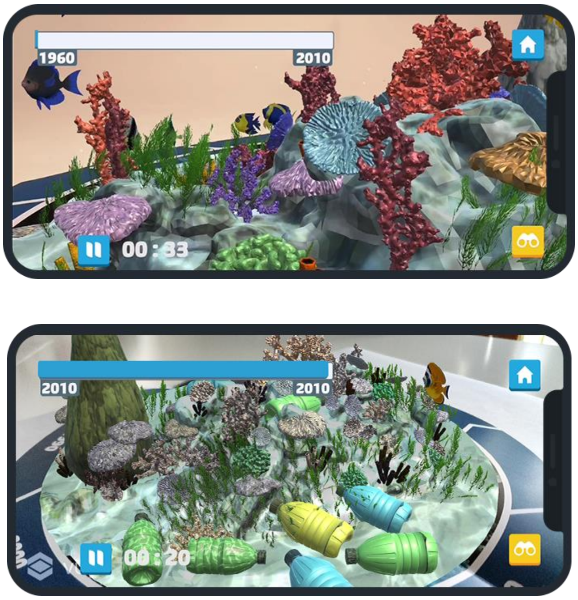

Figure 4: Example of interaction in the Great Barrier Reef AR application.

The architecture of the AR multisensory Changing Earth experience is structured in two main groups of components, as shown in Figure 5.

The first main group of components consists of the AR application, displayed on tablets or smartphones, which allows the visualization of 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.

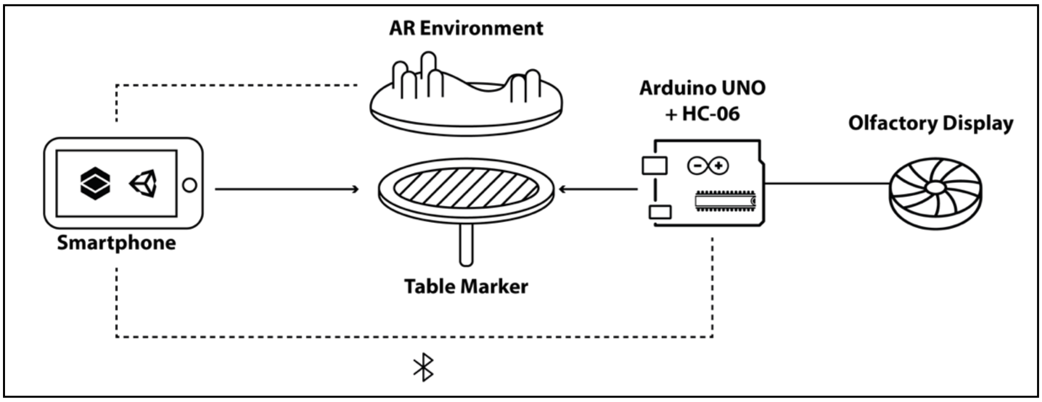

Figure 5: The architecture of Changing Earth experience.

At first opening, the application provides a tutorial and explains to the user the interaction modalities. Also, the user can control some settings, such as language, guide volume, and soundtrack volume (see Figure 6). From this menu, it is also possible to easily shift between the two Changing Earth applications, keeping the user immersed in the experience.

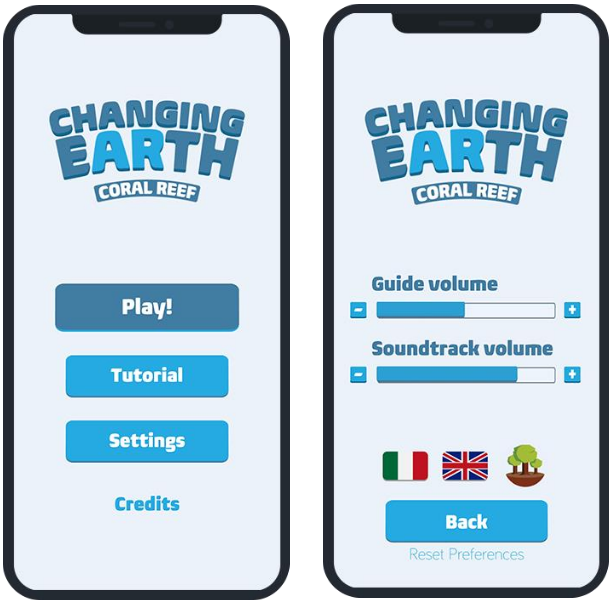

Figure 6: The home page and settings page of the Changing Earth – Coral Reef application.

The AR application is triggered by markers, representing the natural environments, printed on tables. The tables have a round shape to suggest users to follow a path around them, also thanks to the arrows printed on the markers. 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, different content is visualized (see Figure 7).

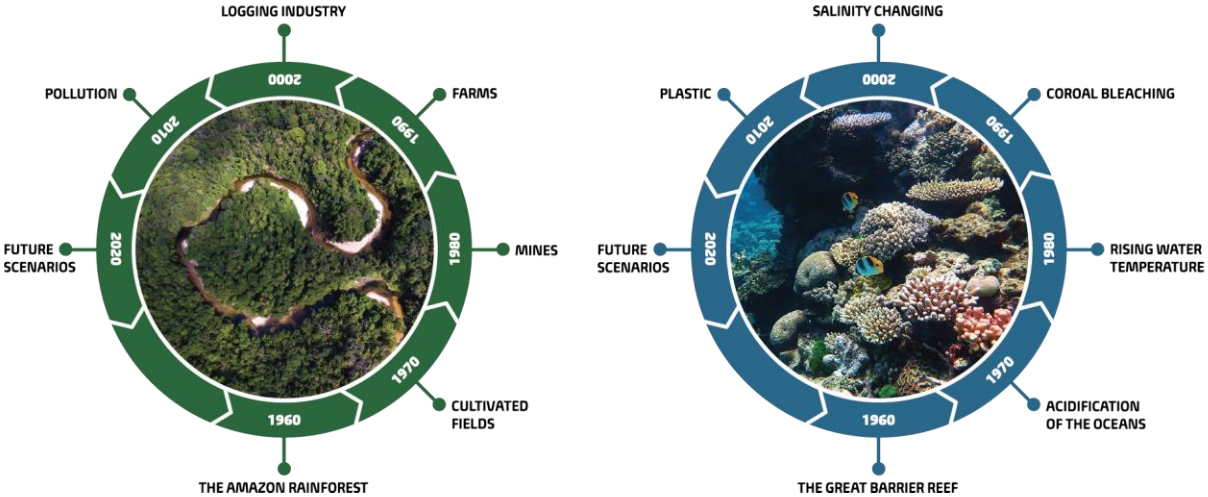

Figure 7: The scheme of the decades and the corresponding digital content.

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 (see Figure 8).

Figure 8: 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;
- providing more information about the content of 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 shows 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 changes in visitors' behaviors.

The second main group of components consists of the table where to place the marker and the four olfactory displays to deliver 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 scent 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, odors have been selected to recall memories of natural environments and provide a pleasant experience at the beginning of the interaction. Then, moving along the experience, negative odors related to human activities and pollution are more and more released to the user.

Concerning the rainforest, the authors selected odors related to plants and flowers (grass, orange blossom, mint, wood) 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, scents related to the sea breeze and sea flowers were selected at the beginning, while odors of dead fish and pollution are released moving forward in the experience.

4 TECHNICAL DEVELOPMENT

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 visualization of the contents.

4.1 Application Development

The application is based on the use of printed markers that allow visitors, when framed with the device, to activate the experience and display Augmented Reality contents. The images on the markers have been chosen due to their expressive potential of the related environment, and for their excellent performance as Vuforia markers (see Figure 9).

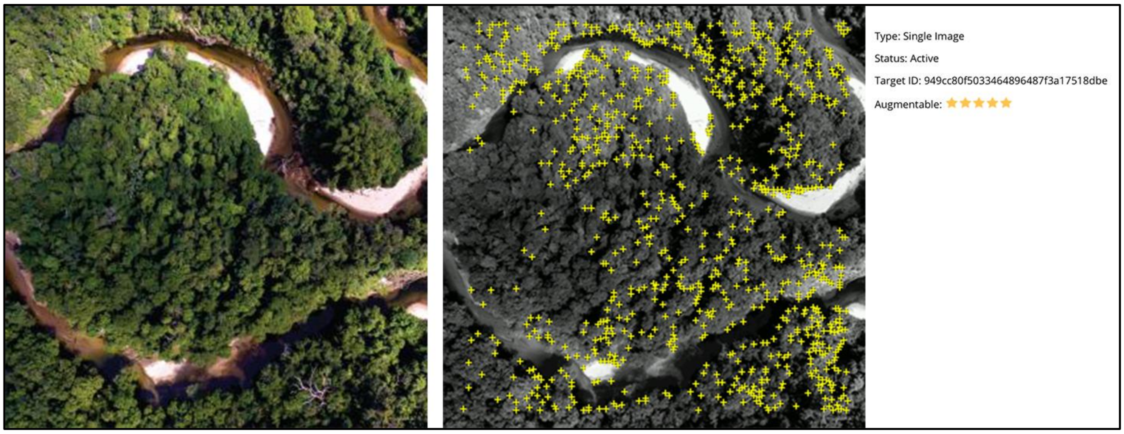

Figure 9: Features of the Amazon Forest marker, which has the 5 stars rating on Vuforia.

Concerning the possibility to use a single marker for different decades, it has been developed by using a script that calculates the relative angle between the Camera (of the device that the visitor is using) and the marker, so that the scene in Augmented Reality can change according to that angle. Specifically, on the basis of the calculated angle, different scenarios and related multimedia contents are displayed.

4.2 Interaction

Both AR experiences (the Amazon Forest and the Great Barrier Reef) have been developed to be experienced with a complete rotation around the table on which the corresponding marker is positioned. If we consider as angle 0 the one that represents where the user starts to frame the marker, we have two kinds of interactions.

First, from angle 0 to angle 270, visitors can watch the scenario evolving over time, with a jump of 10 years every 45 degrees. Some elements in the scene, such as trees in the Forest, will gradually disappear with a *Fade Out*, and other elements will gradually appear with a *Fade In*, such as factories or mines. An audio track is played at each time step. During this phase of the experience, users can also decide to move in the opposite direction, then go back in time instead of moving forward. Consequently, visitors have the full control of what they can see, hear and smell.

Second, from angle 270 to 360, it is possible to view videos that represent hypothetical scenarios on the topics addressed in the experience or return to the homepage.

4.3 Fade Management

In order to handle the fade of a large number of models in the scene, we created two different scripts. The first one is attached to each gameObject we need to fade, and it is responsible to change the alpha value of the MeshRenderer component and enable/disable the gameObject itself.

Then, for organizational purposes, we clustered each gameObject we wanted to fade into folders that represented the year we wanted to show. So, the second script is responsible to find in each folder all the gameObjects with the fade script attached (also considering child for 2 levels) and auto-update the corresponding list in the editor.

By following this approach, when we want to fadeIn or fadeOut all the elements of a specific year, we just need to call a function and the fade is automatically applied to all the elements in the corresponding folder.

4.4 Audio Management

The audio within the scene is managed through a *gameObject* to which an *audioListener* is applied. The tracks are played on three different channels: narrative voice, background sounds and sound effects. When users move on a new decade, the corresponding audio will be automatically selected and played. In the User Interface, users can pause playback, resume playback or listen to the audio. If they lose the tracking, a voice will automatically be played explaining how to track again. Each time a new audio file will be played on a channel, the app will check whether an audio clip is already playing. If so, the previous audio will be stopped and replaced by the new one.

4.5 Fishes Behavior in the Coral Reef Experience

Each fish is a *gameObject* on which an animator is applied to allow the movement of the tail. Besides, a *Collider* component is applied to each fish to allow determining if the fish collides with the ground, corals or other fishes. The movement of the fish within the marine scene is controlled with a script. Each fish moves forward influenced by a random component and by the speed with which the user moves around the table. As soon as the fish collides with an obstacle, the script will automatically recalculate the fish direction to move away. Also, if the *gameObject* goes too far from the center of the environment and is no longer visible from the *Camera*, the script will automatically change its direction and go back.

As the user moves around in the environment, some fish will die due to the acidification, and the changes in water temperature and salinity. The function that manages the death of the fish causes the stop of any movements. Then, the fish rotates 90 degrees and gradually starts floating. Similarly, by moving in the opposite direction around the marker (going back in time) will bring back to life the fish, which will start swimming again.

4.6 Performance and Optimization

The 3D models of the terrains of the two environments have been designed using the "Terrain" tool inside Unity. Then, they have been cut into rounded shapes and resized in order to match the perimeter of the printed images on the markers.

The 3D models in the scene, which are assets available in the Unity store and in other online databases (such as Sketchfab), have been optimized for mobile devices since they presented a large number of polygons that slowed down the application. Instead of uploading different 3D model resolutions (high-res and low-poly) relying on the distance between the user and the model, just an in-between model has been adopted, to reduce the RAM usage and the applications file size. Therefore, the numbers of polygons of 3D models, especially for corals (see Figure 10), have been reduced and the textures have been resized. The level of detail reaches peaks of 3 million vertex in the scenes with more 3D models, that allows the application, running on a high-range Android device, to have an overall in-use stability of 60 FPS. During the shifts from a decade to another the application has a drop rate of 30 FPS, due to the fade of models and the loading of the audio tracks. To avoid lag in the application during these shifts, the function of the script have been called in a sequential mode: first the fade-out and fade-in of the 3D models, secondly pause the playing audio track, thirdly play the next one, then update the timer in the UI and lastly update the images inside the "More info" section. In this way the application is able to run smoothly and the overall experience is not altered by any performance issue.

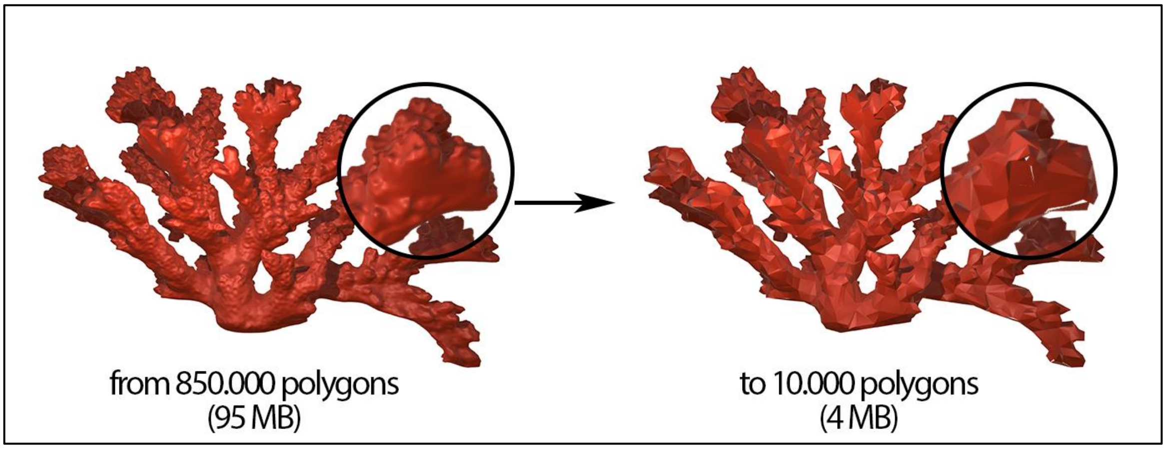

Figure 10: Polygons reduction of a coral 3D model.

Also, 2D images, texts and buttons images have been resampled to be lighter and faster to load. The same approach has been followed for audio clips and videos.

Moreover, the script that determines the *fade In* and *fade Out* of the *gameObject* in the scene also deactivates the 3D models that should not be displayed. In this way, it is possible to reduce the use of RAM memory and improve performances.

4.7 Olfactory Displays

The olfactory displays are connected to an Arduino Uno board, which is placed below the table and communicates with the AR application through a Bluetooth connection (see Figure 11).

Odors are released into the air through 4 fans placed under the table at a distance of 90 degrees from each other. Each centrifugal fan moves the air in one specific direction, allowing to reach only the user who is in front of it. These fans are powered by an external 9V battery and activated by a relay when the odor release is required. Each odor, contained in a pod, is placed inside a case above the fan so that the odor is not dispersed, and the olfactory experience is not altered.

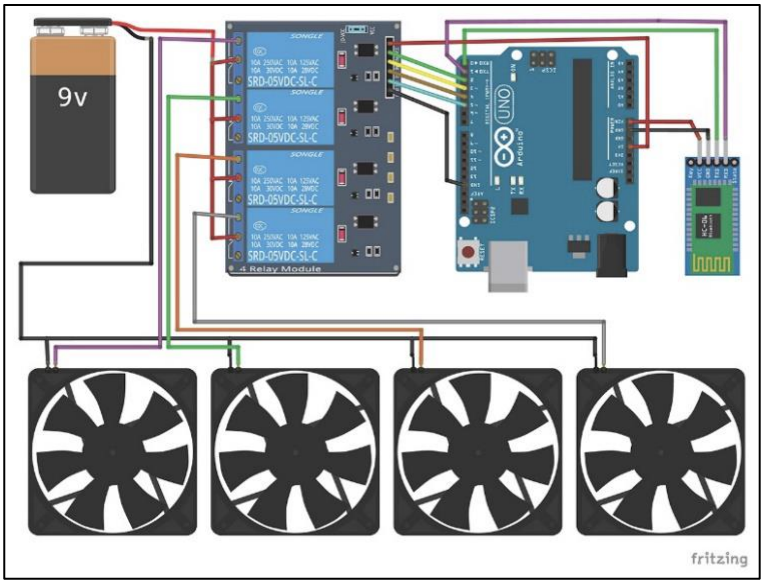

Figure 11: The wiring among the Arduino Uno board, the fans and the other components of the olfactory displays.

The 4-channel relay is connected to the Arduino Uno board and allows to independently control one fan at a time by closing the electrical circuit. An HC-06 module is also connected to the TX and RX pins, which enables a Bluetooth connection between the device and the Arduino serial port. This connection has been managed using the “BT Helper” asset, available in the Unity Asset Store, that constantly sends different strings to the HC-06 module, relying on the angle between the device and the marker.

Therefore, the Arduino board acts as a communication channel between the device and the fans. In particular, when input is sent from the device, the board converts it into a string and checks whether the message corresponds to the string that activates one of the relays. If the signal does not correspond to any string it will be ignored. Otherwise, the corresponding fan is activated, and the odor is released in the air in front of the user.

The HC-06 supports just a single Bluetooth connection, since the experience should be made by one visitor at a time. Indeed, the AR experience has been designed as individual, and by using this approach wrong and excessive mixing of odors in the air is avoided.

5 DISCUSSION AND CONCLUSION

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

Specifically, the described experiences have 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. In fact, the olfactory stimuli have been designed with the purpose of increasing the user's engagement both at a unconscious and conscious level, in order to elicit emotional responses and facilitate the creation of long-lasting memories.

Proper tests on people's perception, psychophysiological and hedonic responses as well as on the educational value of the system, have not been performed yet. However, the authors have collected some preliminary comments and opinions from some users that have tried the applications (see Figure 12). These participants reported a very high level of appreciation of the applications and a high level of pleasantness in using them. In particular, participants stated that the addressed topic is very close to their personal interests and environmental awareness. Nonetheless, they were not aware of much of the information heard during the interactive experience and are satisfied with what they have learned. Regarding the visual part of the AR application, they found it very stable and the digital contents of great entertainment and stimulating to continue using the application. Finally, as far as the olfactory stimuli are concerned, they seemed to be correctly perceived during the interaction. Moreover, according to the participants, olfactory stimuli aroused pleasant sensations in the first phase of the experience, while amplified the feeling of annoyance and sadness in the last steps of the experience. All of these initial reports will certainly need to be properly tested using psychological and neuroscientific methods in the near future.

Figure 12: A participant interacting with the application.

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 implemented to create an emotional link between the readers and objects or 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 educational/historical contents.

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6 REFERENCES

[1] Bordegoni, M.; Carulli M.: Evaluating Industrial Products in an Innovative Visual-Olfactory Environment, Journal of Computing and Information Science in Engineering, 16(3), 2016.
[2] Bordegoni, M.; Carulli, M.; Ferrise, F.: Improving multisensory user experience through olfactory stimuli, Emotional Engineering Vol. 7: The Age of Communication, 201–231, 2019.
[3] Bordegoni, M.; Carulli, M.; Shi, Y.; Ruscio, D.: Investigating the effects of odour integration in reading and learning experiences, Interaction Design and Architecture(s), 2017(32), 104-125.
[4] Damala, A.; Marchal, I.; Houlier, P.: Merging Augmented Reality Based Features in Mobile Multimedia Museum Guides, In: Proceedings of the XXI International Symposium CIPA 2007. CIPA, GRC, 2007, 259-264.
[5] De'ath, G.; Fabricius, K.A.; Sweatman, H.; Puotinen, M.: The 27–year decline of coral cover on the Great Barrier Reef and its causes, PNAS, 109 (44), 2012, 17995-17999, https://doi.org/10.1073/pnas.1208909109
[6] Ferdig, R.E.: Assessing technologies for teaching and learning: Understanding the importance of technological pedagogical content knowledge, British Journal of Educational Technology, 37, 2006, 749–760.
[7] Gallace, A.; Spence, C.: A memory for touch: The cognitive science of tactile memory. In: E. Chatterjee (Ed.). Touch in Museums: Policy and practice in object handling, Oxford: Berg., 2008, 163-186.
[8] Gallace, A.; Spence, C.: Multisensory design: Reaching out to touch the consumer. Psychology & Marketing, 28, 2011, 267-308.
[9] Hirota, K., Ito, Y., Amemiya, T., Ikei, Y.: Presentation of Odor in Multi-Sensory Theater, VAMR/HCII 2013, 2013.
[10] https://blog.beaconmaker.com/5-ways-to-make-your-museum-exhibition-interactive-d302d300808c, last accessed 2020/04/01.
[11] https://climate.nasa.gov/images-of-change, last accessed 2020/04/01.
[12] https://naturalhistory.si.edu/exhibits/bone-hall, last accessed 2020/04/01.
[13] https://secondverse.org/#/after-ice/, last accessed 2020/04/01.
[14] https://www.bbc.co.uk/taster/pilots/civilisations-ar, last accessed 2020/04/01.
[15] https://www.casabatllo.es/en/visit/, last accessed 2020/04/01.
[16] https://www.mnhn.fr/en/virtual-arctic-expedition, last accessed 2020/04/01.
[17] https://www.nationalmuseum.sg/our-exhibitions/exhibition-list/story-of-the-forest, last accessed 2020/04/01.
[18] https://www.nhm.ac.uk/discover/news/2017/april/museum-to-star-in-sky-vr-experience-with-sir-david-attenborough.html, last accessed 2020/04/01.
[19] https://www.wikitude.com/showcase/one-earth-eovisions-augmented-print-media-book, last accessed 2020/04/01.
[20] Hubbell, E.R.: Authenticity & technology in Montessori education. Montessori Life, 18(2), 2006, 16-20.
[21] Kim, D.W.; Nishimoto, K.; Kunifuji, S. et al.: Development of Aroma-Card Based Soundless Olfactory Display, Electronics, Circuits, and Systems, ICECS, 2009.

[22] Krusemark, E.A.; Novak, L.R.; Gitelman, D.R.; Li, W.: When the sense of smell meets emotion: anxiety-state-dependent olfactory processing and neural circuitry adaptation, J Neurosci. 2013, 33(39), 15324–15332.
[23] Maggioni, E.; Cobden, R.; Obrist M.: OWidgets: A toolkit to enable smell-based experience design, International Journal of Human-Computer Studies, 130, 2019, 248-260.
[24] Matsukura, H.; Yoneda, T.; Ishida, H.: Smelling Screen: Technique to Present a Virtual Odor Source at an Arbitrary Position on a Screen, IEEE Virtual Reality 2012, 2012.
[25] MeeCham, P.; Stylianou, E.: Interactive Technologies in the Art Museum, Designs for Learning, 5(1-2), 2012, 94-129.
[26] Micaroni, L.; Carulli, M.; Ferrise, F.; Gallace, A.; Bordegoni, M.: An Olfactory Display to Study the Integration of Vision and Olfaction in a Virtual Reality Environment, Journal of Computing and Information Science in Engineering, 19(3), 2019.
[27] Montessori, M. (1964) The Montessori method, New York, Schocken Books, Inc.
[28] Nakamoto, T.: Human Olfactory Displays and Interfaces: Odor Sensing and Presentation, Information Science reference, 2013.
[29] Nakano, J.; Narumi, T.; Tanikawa, T.; Hirose, M.: Implementation of on-site virtual time machine for mobile devices. In: Virtual Reality (VR) 2015, 2015.
[30] Narumi, T.; Nishizaka, S.; et al.: Meta Cookie+: An Illusion-Based Gustatory Display, Virtual and Mixed Reality, 2011, 260-269.
[31] Pecher, D.; Zwaan R.A.: Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thinking, Cambridge University Press, 2005.
[32] Pedlowski, M.A.; Dale, V.H.; Matricardi, E.A.; Pereira da Silva, E.: Patterns and impacts of deforestation in Rondonia, Landscape and Urban Planning, 38 (3–4), 1997, 149-157.
[33] Prochaska, J.O.; DiClemente, C.C.: Stages and processes of self-change of smoking: toward an integrative model of change, Journal of consulting and clinical psychology, 51(3), 1983, 390-395.
[34] Rae, J.; Edwards, L.: Virtual reality at the British Museum: What is the value of virtual reality environments for learning by children and young people, schools, and families?, MW2016: Museums and the Web, 2016.
[35] Ranasinghe, N.; Shamaiah, K.; Jain, P.; Tram, N.; Tolley, D.; Liangkun, Y.; Tung, C.; Yen, C.; Do, E.; Koh, R. (2018), A Demonstration of Season Traveller: Multisensory Narration for Enhancing the Virtual Reality Experience. Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18), New York, NY, USA, D114, 1–4. DOI: https://doi.org/10.1145/3170427.3186513
[36] Spence, C.; Driver, J.: Crossmodal space and crossmodal attention, Oxford University Press, 2004.
[37] Spence, C.; Gallace, A.: Making sense of touch. In: E. Chatterjee (Ed.). Touch in Museums: Policy and practice in object handling, Oxford: Berg., 2008, 21-40.
[38] Vrettakis, E.; Kourtis, V.; Katifori, A.; Karvounis, M.; Lougiakis, C.; Ioannidis, Y.: Narralive– Creating and experiencing mobile digital storytelling in cultural heritage, Digital Applications in Archaeology and Cultural Heritage, 15, 2019.