Promoting Awareness on Sustainable Behavior Through an AR-Based Art Gallery

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Abstract. This paper presents "Augmented Gallery", an art gallery in the form of a networked, AR-based, audio-visual system, which was devised to convey the visitors a clear message about the urgency of taking action to address environmental threats such as pollution, climate change, and biodiversity loss. The system was designed to both entertain and educate the visitors, empowering them to understand how unsustainable behaviours may affect our lives in the future and emphasize the need to take relevant actions for building a more environmentally sustainable world. Augmented Gallery consists of an AR app running on networked smartphones used by visitors. The app displays, at visual and auditory level, scenes representing various healthy environments as well as, via user interactions, their counterpart affected by the consequences of an unaddressed climate change and unsustainable human behaviour, exposing predictions based on the Intergovernmental Panel on Climate Change climate report. A user study was conducted, where the gallery was evaluated during two public events. The results showed that opinions about Augmented Gallery were generally very positive. Furthermore, visitors admitted that attending the gallery increased their awareness on environmental issues and their consequences on the planet.

Keywords: Augmented reality · Sustainability · Persuasive technology

1 Introduction

Art has a unique power to convey messages and throughout history artists have intelligently exploited this power in their masterpieces. The recent advancements in Augmented Reality (AR) technologies are not only impacting contexts such as industry 4.0 or learning, but are also fostering new possibilities for artistic creation. In particular, the use of AR in the art experience is creating unique new opportunities to raise awareness and reach audiences about various topics. As of today, a very timely topic is that of climate change and its consequences. Various artists worldwide are using their craftsmanship, mastery and virtuosity to create awareness of environmental issues. This includes also AR-based art

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forms (see e.g., exhibitions at Singapore ArtScience Museum's Climate S.O.S – Season of Sustainability[1]).

Various studies have investigated the use of AR applications in cultural heritage [11], music performance [14,16], or other artistic contexts [9]. Whereas those studies involved different hardware technologies (including handheld devices, smart glasses, or AR-headsets [2,20]), common to all the developed systems is the utilization of AR technologies to superimpose virtual content to a scene (e.g., annotations to a painting [15]), or objects (e.g., virtual objects superimposed to items in museums [6,13]). However, to the best of authors' knowledge, little attention has been devoted by the artistic and research community to the use of AR technologies as a medium to augment an environment "as such", rather than objects present in it. Indeed, despite this is not its primary use, AR has the possibility to generate virtual content that instead of augmenting a real content, substitutes it. This enables the virtual reconfiguration of a real environment into a virtual one, which is nevertheless linked to the real scene.

On the other hand, various studies have investigated the experience of users in interacting with AR technologies involved in contexts of museums or art galleries (see e.g., [4,7,10]). However, thus far the specific topic of climate change has been little addressed by the AR community dealing with art. According to Coen et al. [5], AR has the potential to help educate people on climate change and promoting sustainable behaviours. In recent years a handful of artists have employed AR technologies to attempt to raise awareness of climate change, under the premise that such a technological medium would help audiences better "experience" it and its consequences.

In this paper, we first explore the concept of using AR in a mobile phone app to enable the repurposing of environments into AR-based art galleries. Secondly, we apply this concept to the artistic representation of the topic of climate change, with the ultimate aim of educating and raising the visitor's awareness towards this timely issue. We position our system, which we call "Augmented Gallery", as a persuasive technology [8,12] because by allowing visitors to experience in novel ways the environmental issues, it is intended to increase knowledge about them and consequently modify users' attitudes or behaviours. Finally, we assess the developed technology and its conveyed user experience via an ecologically-valid user study conducted during a set of artistic exhibitions.

2 Augmented Gallery

Augmented Gallery is a networked AR-based system developed to convey the visitors a clear message about the urgency of taking action to address environmental threats such as climate change and biodiversity loss. The system was designed to both entertain and educate the viewers, empowering them to understand how unsustainable behaviours may affect our lives in the future and emphasize the need to take relevant actions for building a more environmentally sustainable

[1] https://www.unenvironment.org/news-and-stories/story/new-cleanseas-augmented-reality-experience-merges-real-world-and-virtual.

world. To achieve this goal, Augmented Gallery uses interactive virtual objects to show to the viewer the consequences of an unaddressed climate change, exposing predictions based on the Intergovernmental Panel on Climate Change (IPCC) climate report[2].

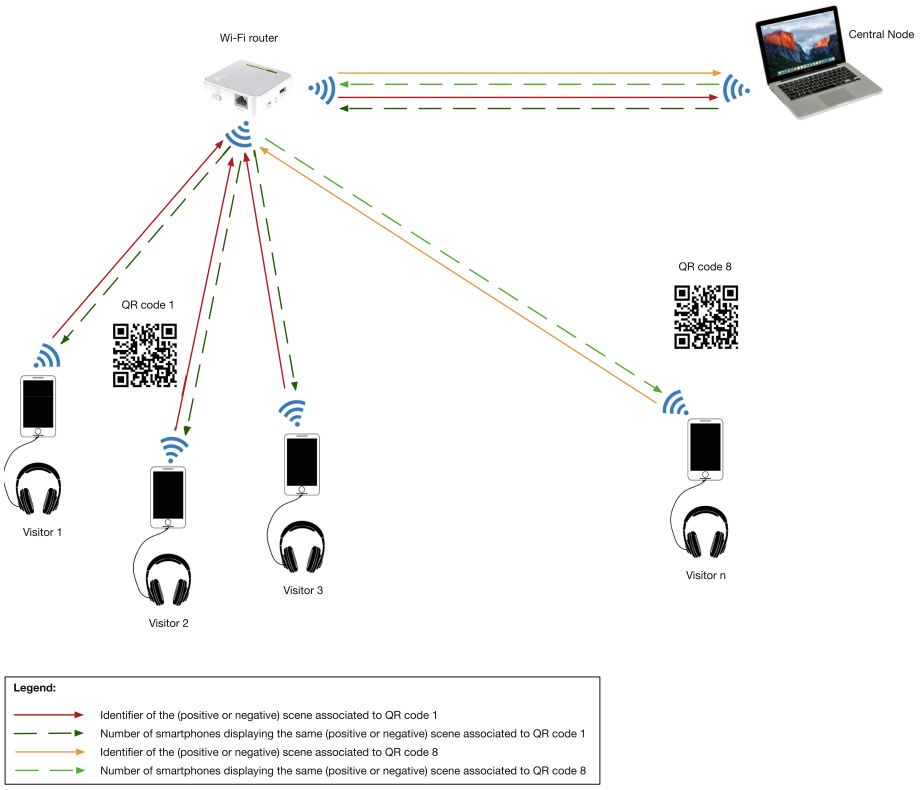

Fig. 1. A schematic representation of the networked architecture of Augmented Gallery, including its main components and data flow. Each QR code represents a scene.

Augmented Gallery is a networked system consisting of smartphones (used by the visitors), which run a dedicated audio-visual AR app (see Fig. 1). The app consists of eight scenes. Each scene is defined by a unique QR code, freely placeable on walls of whatever environment (see Fig. 2). The placement of the QR codes is arbitrary and each QR code can be placed independently from one another. The scenes represent various harmonious environments (the "positive environments") as well as their counterpart affected by the consequences of an unaddressed climate change and unsustainable human behaviour (the "negative

[2] Synthesis Report of the IPCC Fifth Assessment Report of 2014, https://www.ipcc.ch/.

environments"). The latter include scenarios like rising sea levels, droughts, acid rains, poisonous smog, and floods. Each negative environment was created from the positive one by changing it to reflect the outcomes of the climate change hypothesize by IPCC.

Fig. 2. A picture of a participant interacting with Augmented Gallery.

At visual level, the AR app is based on two types of metaphors. The first type consists of a window-like object (see Fig. 3). The QR code placed on a wall generates a window in which a small 3D environment is shown. The window is rendered so to hide a significant part of the virtual environment from the viewers, forcing them to change perspective to be able to see the whole environment: the app was designed to respond to various kinds of interactions of the viewers, who could get close or far, or move to left, right, top and bottom to change the angle of view (see Fig. 4). Another interaction is the user's touch onto the virtual glass of the window (i.e., onto the smartphone touchscreen), which enables the change of scene from the positive environment to the negative one, and vice versa. When the visitor encounters for the first time a QR code, the displayed scene shows an environment untouched by pollution and climate change or in harmony with human activities. Upon the user's touch, the virtual glass slowly brightens to the point in which it becomes a white opaque wall. At this point the scene is replaced with the corresponding negative environment. The glass slowly returns to its normal transparent state and the changed scene is displayed.

The second type of metaphor is diorama (see Fig. 5). Dioramas are miniature models of various scenes or objects, often encapsulated in a glass showcase. These items do not feature the same rendering effect of the scenes with windows metaphors, and all the scene is show instantly to the viewer. Moreover it has the possibility to grow or shrink with a pinch gesture on the touchscreen allowing the viewer to be able to see the details. The virtual dioramas also feature a changing

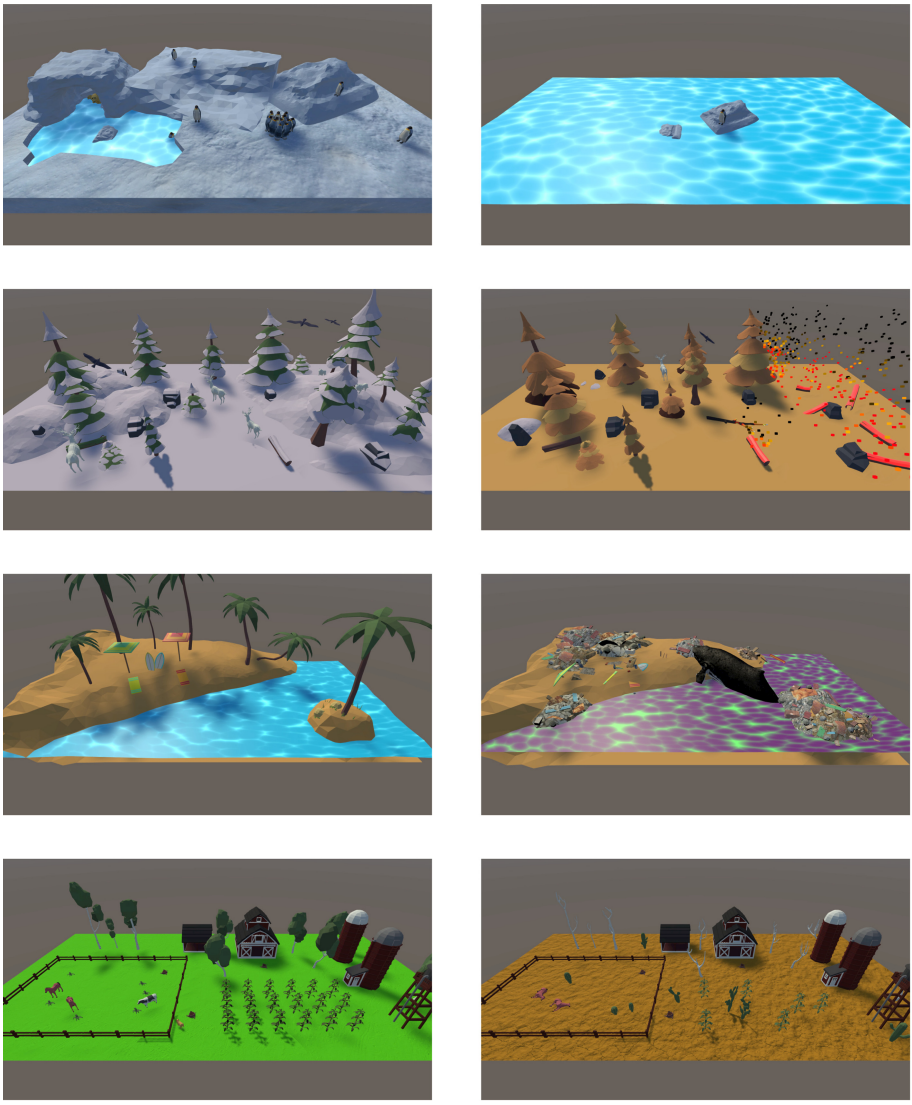

Fig. 3. Screenshots of the AR scenes based on the windows metaphor. Left: the healthy environment; right: the same environment affected by climate change consequences.

environment, which can be changed in the same fashion as the windows by touching the smartphone touchscreen.

At auditory level, the AR app provides a soundscape[3] for each of the positive and negative scenes described above. The soundscapes were ad-hoc composed

[3] The term "soundscape" refers to the sonic environment, the aural counterpart of the term landscape referred to visually-related items in an environment.

Fig. 4. Screenshots of different perspectives of one of the AR scenes. On the left the scene is shown from a front view, on the right the perspective is changed, which allows to see other parts of the environment not visible using the front view. The blue background was not rendered, but the real world tracked by the mobile camera was visible. (Color figure online)

[18,19] using audio content retrieved from the online repository Freesound.org [1]. The sonic material reflected the virtual content visually displayed on the smartphones screens. The soundscapes of the positive scenes were designed to be radically different from those of the corresponding negative scenes. The choice of using a sonic layer additional to the visual AR content was due to the aim of achieving a more immersive experience.

The smartphones present in the gallery are connected over a Wi-Fi link to a central node. The central node (which can be another smartphone or a computer) has the function to receive/route messages from/to the other smartphones. This network infrastructure is only utilized to create a dynamic soundscape, which varies in function of the number of visitors exploring a same scene (see Fig. 1). Specifically, in the default configuration (when only one visitor is in front of a scene), only one audio track is played back as soon as the QR code is recognized by the software and the scene is shown to the viewer. As soon as more visitors are exploring the same scene, a new audio track is played on top of the previous ones. This design choice of creating more complex soundscapes as a function of the number of viewers aimed at increasing social presence [17] leveraging the audio channel.

To enable communication among the devices in the network we utilized the Open Sound Control protocol (OSC) [21]. The AR app was created in Unity and was built only for Android-based mobile phones. It used the third party tool Vuforia, one of the best AR toolkit available for Unity, as well as the plugin OSCJack, a lightweight implementation of the OSC protocol. Only static IP were used (assigned by the router), which avoided to create a local network session within the Unity application that would have increased the burden on the hardware and, as a consequence, decreased the performances.

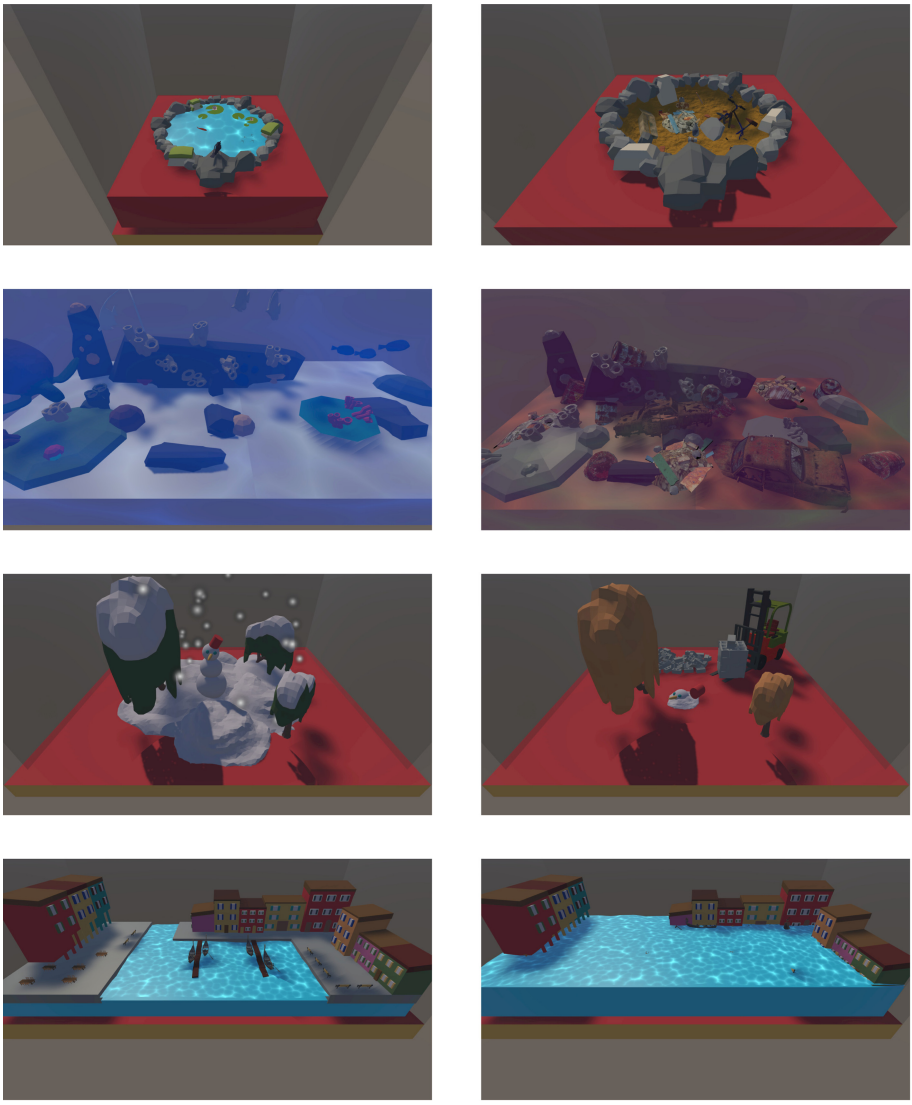

Fig. 5. Screenshots of the AR scenes based on the diorama metaphor. Left: the healthy environment; right: the same environment affected by climate change consequences.

Augmented Gallery was developed only for Android-based smartphones. The minimum and recommended requirements to run the app on Android-based devices are listed in Table 1.

Table 1. Minimum and recommended requirements to run Augmented Gallery on Android-based devices.

	Minimum requirements	Recommended requirements
Operating system version	Android 7 (Nougat)	Android 9 (Pie)
RAM	4 GB	6 GB
Memory	140 MB	140 MB
Resolution	720 × 1280 pixel	2340 × 1080 pixel
System chip	HiSilicon Kirin 659	Snapdragon 855
GPU	ARM Mali-T830 MP2	GPU Adreno 640

3 User Study

The user study aimed at investigating whether it is possible to convey a message about climate change and its consequences by means of an art gallery entirely based on AR and wireless network technologies. Augmented Gallery was tested twice was set up in two places: a coffee shop and at one of the halls of the University of Trento, which provided ecologically-valid settings for an art exhibition (see Fig. 2). A total of 24 visitors (aged between 18 and 40, mean age = 22.3) took part to the evaluation (13 males, 8 females, 3 preferred not to say their gender).

At the outset, visitors were asked to download and install the app on their smartphones as well as to wear the headphones. They were also instructed about the interactions afforded by the app. As the app could run only on Android-based smartphones, the participants using iOS-based smartphones were given a smartphone pre-configured with the app. Similarly, participants who did not have a pair of headphones were provided with them by the experimenter. Each participant was invited to freely explore the gallery, starting from a point in the gallery at his/her choice (in this way the order of the visited scenes was randomized).

After having explored the whole gallery, participants were asked to fill an ad-hoc questionnaire. The questionnaire comprised demographic information such as age and gender, as well as the level of familiarity with AR technologies and the degree of familiarity with the climate change topic (the last two items were evaluated on a 7-point Likert scale, with 1 = little familiar, 7 = very familiar). Moreover, the questionnaire comprised the following questions to be evaluated on a 7-point Likert scale (with 1 = strongly disagree, 7 = strongly agree):

- *[Learning.] I learned something new about climate change and its consequences thanks to this AR exhibition.*
- *[More Informed.] This AR exhibition made me more knowledgeable about the climate change issue and its consequences.*
- *[Motivation.] This AR exhibition stimulated my curiosity to learn new things about climate change and its consequences.*

- *[Awareness.] This AR exhibition improved my awareness of the climate change issue and its consequences.*
- *[Behavioural Change.] This AR exhibition can change the way I think or behave in relation to the climate change issue and its consequences.*
- *[Immersion.] I was very engaged with the AR exhibition.*
- *[Recommendation.] I recommend this AR exhibition to others.*
- *[Appreciation.] I appreciated this AR exhibition.*

In addition, participants were asked to answer the following open ended questions: *"What did you enjoy the most about the exhibition?"; "What did you enjoy the least about the exhibition?"*. Finally, participants were also allowed to leave an open comment about their experience. On average, participants took 30 min to complete the experiment.

3.1 Results

The responses of the questionnaire items "familiarity with AR technologies" and "familiarity with the climate change topic" received relatively low rankings (respectively mean = 3.2, standard error = 0.28, and mean = 4, standard error = 0.31) indicating that on average participants did not have too much direct experience with AR technologies and had little awareness about the climate change topic.

Figure 6 illustrates the results of the other questionnaire items. As it is possible to notice from the figure, the evaluations were all above neutrality. Through the gallery, participants felt to have learned something new about climate change

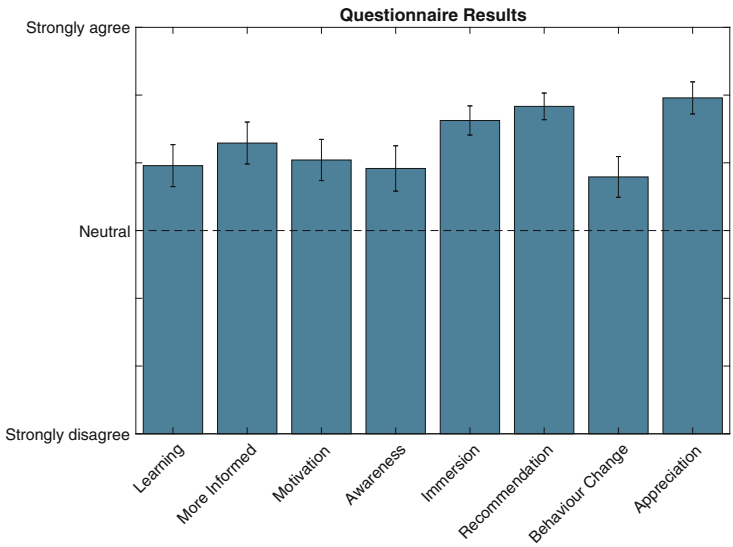

Fig. 6. Mean and standard error of the questionnaire items (evaluated on a 7-point Likert scale).

and its consequences. They reported that the gallery made them more knowledgeable about the showcased topic, motivated them to learn more and improved their awareness about it. Evaluations also indicate a potential for behavioural change that the exhibition could trigger. Results also show that the gallery was welcomed by visitors, in terms of appreciation, engagement and potential for recommendation to other visitors.

Interestingly, high linear correlations were found among the responses to some of the questionnaire items. These were identified by means of a Pearson's correlation test. Table 2 shows the highest among the significant correlations between the questionnaire items. It is worth noticing that high correlations were found between items related to learning aspects and items related to behaviours. This suggests that stimulating knowledge acquisition about climate change and making participants more informed about it via an artistic installation has the potential to rise the public awareness on such a topic. As a consequence, according to the results, this may induce sustainable behaviours in individuals.

Table 2. The highest correlations between questionnaire items, identified with a Pearson's correlation test.

Pair	R	p
Learning-more informed	0.76	<0.001
Learning-motivation	0.79	<0.001
Learning-awareness	0.7	<0.001
Learning-behavioural change	0.6	<0.01
More informed-motivation	0.61	<0.01
More informed-awareness	0.8	<0.001
More informed-behavioural change	0.75	<0.001
Motivation-awareness	0.68	<0.001
Motivation-behavioural change	0.62	<0.01
Awareness-behavioural change	0.84	<0.001

The evaluations illustrated in Fig. 6 and the correlations reported in Table 2 are also reflected in the participants' answers to the open-ended questions. These responses were analyzed using an inductive thematic analysis [3]. The analysis was conducted by generating codes, which were further organized into themes that reflected patterns, as described below.

Enjoyment and Engagement. Five participants commented to have appreciated the experience of exploring Augmented Gallery, and to have felt engaged with it (e.g., participant 9 stated: *"I liked the app because it teaches about climate change."*; participant 23 reported *"I enjoyed being able to see the environments before and after the consequences."*).

AR Medium Appreciation. Four participants appreciated the fact that the AR medium was utilized to convey the messages about sustainability and found

this approach original (e.g., participant 17 reported *"It is a different approach on a topic that is usually addressed with other and less interactive tools"*; participant 18 stated *"it is a great app to show how dangerous climate change would affect the earth and the living creatures on it."*).

Increased Awareness. Six participants reported that the exhibition was effective in making them reflect on the climate change issue and about the needs of a sustainable behaviour of mankind. (e.g., participant 2 stated: *"I enjoyed the fact that the app allows people to see what pollution entails and I hope that people put more awareness about it and could adopt more ecological behaviours."*; participant 13 stated *"It was inspiring for me to see how to pass from a normal environment to a changed one and noticing what could remain of it."*; participant 22 reported *"It is a great initiative to represent the future planet if we don't modify our behaviours."*).

4 Discussion and Conclusions

Augmented Gallery differs from most AR applications in that it does not augment objects in a real environment with additional virtual content (e.g., textual annotations or virtual objects that enhance the real objects with contextual information). Rather, it completely substitutes a part of the real environment (typically a wall) with a virtual scene (e.g., a virtual painting). This allows to turn any environment in an art gallery, by simply placing in it the QR codes at the positions where the virtual scenes are intended to be displayed.

Our system was conceived to sensitize visitors towards climate change, with the ultimate goal of triggering sustainable behaviours in them. The results of the evaluation, conducted in ecologically-valid contexts, revealed that visitors' opinions about Augmented Gallery were generally positive. In particular, visitors admitted that attending the gallery increased their awareness on environmental issues and their consequences on the planet and its lifeforms.

Nevertheless, it is important to notice that our system presents technical limitations. We chose the smartphone as a platform for our system given its use much more widespread compared to smart glasses or dedicated AR-headsets. The public is already familiar with the use of smartphones and the distribution and installation of app is trivial. The main drawback of using smartphones is the limited performance of their hardware, which forces the designers to limit the complexity of the AR content displayed in real-time, as well as the scarcity in diversity of input methods, which are limited to touchscreens, cameras and movement sensors.

Overall, it is possible to conclude that Augmented Gallery was successful in evoking awareness among visitors about the climate change and its consequences. Whether or not our artistic creation was actually capable of fostering sustainable behaviours in the visitors was not the object of this study. Therefore, it remains an open question whether Augmented Gallery would have a meaningful impact on visitor's attitudes and behaviours. Nevertheless, we agree with Coen et al. [5]

that there is a lot of potential for social action using AR, in particular to give us a better understanding of our impact on the planet.

In future work, encouraged by the success of the exhibitions reported by visitors, we plan to perform other exhibitions involving Augmented Gallery, to allow audiences to immerse themselves in the challenge of tackling the climate change problem. We also plan to use the same architecture developed for Augmented Gallery, to explore other relevant topics, with the aim of artistically conveying other messages for positive social impact. Via AR-based art it is possible to deliver some incredibly powerful messages, and as a consequence create great awareness and engagement on climate-related communications. It is the hope of the authors that this paper could inspire others to create artistic installations leveraging the AR medium to convey positive messages about the benefits resulting from sustainable behaviours.

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