BEYOND THE OVERVIEW EFFECT: A VIRTUAL REALITY EXPERIENCE FOR SUSTAINABILITY AWARENESS IN DECISION-MAKING

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ABSTRACT

The challenges of sustainable development require a consistent transformation of decision-making practices in society and in the industry. In this regard, Virtual Reality (VR) is an effective tool, providing experiences that are not accessible in the real world. The overview effect is a feeling of interconnectedness and responsibility towards our planet and its inhabitants described by astronauts after seeing the Earth during spaceflights. We present a VR application merging the overview effect with data visualization. We illustrate the design process and perform a pilot test to assess the emotions raised by the VR experience. Furthermore, we report feedback from design engineering and sustainability experts discussing the applications' potential in decision-making contexts, including product development processes.

Keywords: Sustainability, Virtual reality, Human behaviour in design, Decision making, Emotional design

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1 INTRODUCTION

The present challenges of sustainable development objectives require consistent transformations at societal, organizational and individual levels (Cavagnaro and Curiel, 2017). Despite this need has been acknowledged by an increasing majority of the global population, we often struggle to make sustainability a priority and introduce more pro-environmental and pro-social choices in our daily life (ElHaffar, 2020). This is especially true considering professionals working in industries affected by strict regulations and standards that may hinder sustainable change (EASA, 2019). Virtual Reality (VR) has been widely recognized as an effective tool to raise awareness and stimulate sustainable attitudes and behaviour, both for the general public and for technical education and professional sectors (Scurati et al., 2021). Importantly, one of the areas that could benefit from the use of VR applications is engineering design, in particular, considering decision-making. Engineers and designers can use the interactive visualization provided by VR tools to make more conscious choices, taking into account a variety of environmental, social, and economic aspects. This shift in consciousness is enabled by VR experiences due to their ability to pop into our lives for a brief moment and change the way we think, feel and possibly act (Scurati et al., 2021). Experiences that would require travelling long distances, purchasing expensive equipment and undergoing intensive training and preparation, are made available to a wide public and can be rapidly set up for use. Examples include the exploration of the seabed (Ahn et al., 2016), tropical forests (Minocha et al., 2017), and arctic areas (Barnidge et al., 2021). It is also possible to make users experience situations that would be extremely dangerous in destinations that would be complex to reach, like in the case of areas affected by armed conflicts and cities destroyed by wars (Gürerk and Kasulke, 2018). However, designers could be even more ambitious and take users on a journey to space. While the previous examples obviously raise awareness by showing how human actions are affecting our ecosystems and the lives of millions of people, the use of spaceflight for similar purposes might be less straightforward to understand. The desired outcome of such an experience, which has the potential to deeply transform human perspective, is called the overview effect (Stepanova et al., 2019). The overview effect is the feeling described by several astronauts coming back to Earth. Our planet appears stunningly beautiful and contrasting with the dark space, it looks fragile, national boundaries and conflicts disappear, a sense of unity and harmony pervades the spectator. This leads to an increased sense of care and responsibility towards the environment, other humans and living beings, and our collective future as inhabitants of the Earth. For these reasons, spaceflight experiences providing the overview effect have the potential to support sustainable attitudes in a triple bottom line perspective, highlighting the interconnectedness among environmental, social, and economic systems. Merging these aspects is usually complex and requires the representation of different aspects and mechanisms. In this case, a single and relatively simple experience could be the starting point to enable a complete sustainability perspective. Due to the growing research efforts to support sustainable development and the interest in the use of VR for this purpose, the overview effect started to gain the attention of the scientific community. Recent studies explored the possibility to study its effects through VR applications (Chirico et al., 2018), as well as its potential in the development of transformative tools, including guidelines for the design of overview effect VR experiences (Stepanova et al., 2019). However, they could be implemented through a variety of designs for different potential target users and contexts. To the best of our knowledge, none of the previous studies explored the overview effect's potential in the area of data visualization for sustainable decision-making for engineering design.

We present a case study of a VR application to support sustainability awareness merging the overview effect with data visualization. The aim of this work is to assess the emotional aspects of the VR application through a simple case study using pollution data, discussing possible applications with the participants. The study is therefore meant to be a pilot test to assess the potential of the overview effect to support awareness in decision-making processes in enterprises, in particular for product and Product Service System (PSS) development. The paper is organized as follows: Section 2 discusses related works considering the use of VR for sustainability awareness and sustainable behaviour change and the overview effect of VR. Section 3 presents the design of the VR application following specific guidelines found in the literature. Section 4 describes the pilot test with engineering design and sustainability experts and the results of the questionnaire for emotional assessment. Section 5 reports the results of interviews conducted with the test's participants regarding the potential of similar applications and possible design directions, followed by the discussion and conclusions.

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2 RELATED WORKS

2.1 VR for sustainability awareness and behaviour change

Several works investigated the use of VR to support sustainability awareness, sustainable behaviour and attitudes change. VR allows showing the consequences of sustainability issues far away in space and time (e.g., remote areas of the world and/or in a distant future) that the user could not experience in the real world (Scurati and Ferrise, 2020). An example is visualizing the effect of climate change in Greenland (Barnidge et al., 2021). In the case of professionals and stakeholders, VR can enable visualizing the effects of their decisions (Scurati and Ferrise, 2020). Importantly, the potential of VR relies on the possibility to depict dramatic phenomena in an extremely realistic way, as well as to represent in alternative ways phenomena that are less tangible and hard to visualize in reality. The former is the case of presenting hypothetical dystopic scenes of natural disasters due to climate change (Ferris et al., 2020). The latter is the case of pollution and seismic data, which can be represented by introducing elements of Augmented Reality (AR) into a virtual environment, for instance augmenting a virtual map (Havenith et al., 2019). Addressing emotions can play a fundamental role in supporting sustainable behaviour and awareness as widely discussed in the review presented by Scurati et al. (2021). This can be done by stimulating the user's affection towards the environment (nature), as well as their empathy towards other humans (Gürerk and Kasulke, 2018) and living beings (Ahn et al., 2016). According to Zelenski and Desrochers (2021), positive and self-transcendent emotions (e.g., awe, compassion, and gratitude) are particularly effective. Noticeably, they can be related to the overview effect (van Limpt-Broers, et al., 2020).

2.2 The overview effect in VR

The emotional effect of the earth view from space has been studied by Chirico et al. (2018) in their work regarding awe (i.e., a feeling astonishment, wonder, and connectedness that humans experience of in front of wide spaces and elements). Awe is in fact a predictor of the overview effect (van Limpt-Broers, et al., 2020). The study by Quesnel et al. (2019) shows how awe can increase the human connection with nature, potentially improving pro-environmental and pro-social behaviours, as well as wellbeing. Their VR experience was based on different steps including the visualization of natural scenes (forests and oceans). Stepanova et al. (2019) proposed a set of guidelines to design overview effect experiences in VR, describing a series of design elements, how and in which order they should be presented, as well as possible strategies and features to implement to satisfy the requirements. These guidelines are used by van Limpt-Broers, et al. (2020) to design an educational experience for children, showing how the overview effect positively affects learning. De Vries (2021) discusses the potential of the overview effect to boost creativity and problem-solving skills, by merging the calming view of the earth with the constant preparedness for possible problems in extreme space conditions. This could be beneficial for product developers and other decision-makers operating in complex contexts and under time pressure.

3 DESIGN OF THE VR EXPERIENCE

3.1 Overview effects design and data visualization of human decisions' impact

To design the VR application the authors used the guidelines provided by Stepanova et al. (2019), which are listed in Table 1, along with the corresponding elements in the VR application. The guidelines regard four aspects. How to begin the VR experience, how the earth should be viewed, how the surrounding environment should appear, and how users should psychologically and physically perceive themselves in the environment. The objective of this VR experience goes beyond the potential of the overview effect itself on sustainable attitudes and behaviour. Rather, it aims at leveraging the overview effect to support decision-making, developing an environment to visualize the effects of possible design. However, the first step is to assess whether the overview effect could make the visualization of human behaviour and decisions' impact more effective by increasing awareness through an emotional experience. Hence, the first prototype should include the presentation of relevant data related to sustainability aspects that are affected by design engineering choices. For this case study, we selected the levels of NO2 due to its relevance for the transportation and industrial sectors that has recently been discussed due to the altered emissions during the COVID 19 pandemic (Bassani et al., 2021). The strategy used is to augment the VR scene with additional data, merging the potential

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of VR and AR, like done by Havenith et al. (2019). The graphic representatio of NO2 levels was taken from Windy (www.windy.com/).

Table 1. The guidelines by Stepanova et al. (2019) and corresponding elements in the application.

Experience aspect	Design guideline	Elements in the VR application
BEGINNING	***The experience should start with:*** 1 Personal connection (familiar place); 2 Fear (surprising and scary events);	1 The experience starts in a typical local scenario containing natural, architectural, and national elements; 2 The user suddenly starts moving upwards, while the scene fades into dark, a loud rocket noise plays.
EARTH	***The earth should appear:*** 3 Surprisingly revealing its beauty in a moment; 4 Detailed features contrasting with the environment; 5 From different angles and perspectives; 6 Like a living organism (moving patterns);	3 The space scene fades in after the darkness, slowly revealing the earth view far away; 4 The earth surface is detailed, changes according to lighting, colors are vivid; 5 The user can navigate closer and around the earth; 6 The earth rotates and its layers are animated (e.g., clouds)
ENVIRONMENT	***The environment should appear:*** 7 Vast, extended far away from the user; 8 Aesthetically impressive (dreamlike);	7 A wide dark space sorrounds the user; 8 A beautiful starfield can be observed all around the space;
USER PERCEPTION	***The user should experience:*** 9 Embodiment and self-relevance; 10 Weightlessness; 11 Hearing their own body sounds (priming) in the space silence.	9 The sense of presence is enhanced by multisensory feedback and control changing through the different scenes; 10 The view moves up while going to space, the user is not able to control their movements and walk into the scene; 11 An heartbeat sound starts playing when the earth appears.

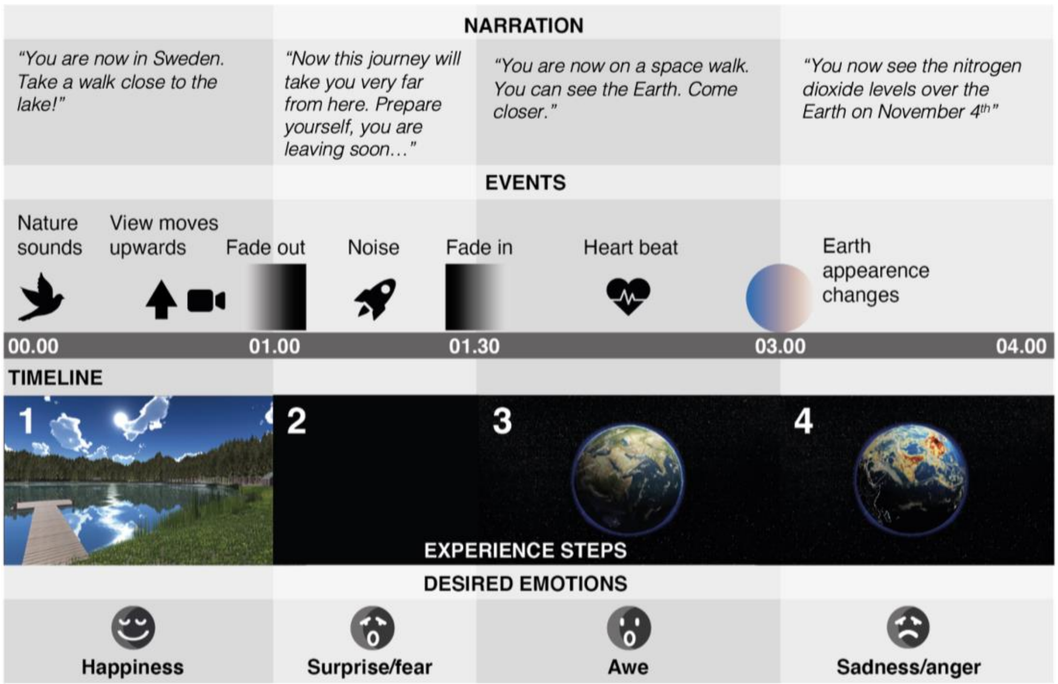

Figure 1. The 4 steps of the VR experience on a timeline along with the corresponding narrations, events, and desired emotions raised by each step.

Figure 2. The first step of the application. Left: a detail of national elements, centre: the VR scene, right: transition towards step 2 (the camera moves up and the scene gets darker).

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3.2 Development of the VR application

After selecting the elements composing a VR experience, they were assembled in a storyline creating a specific sequence of scenes, events, and a narrative. A similar process was used for the overview effect experience designed by Quesnel et al. (2019). Figure 1 represents the steps of the VR experience along a timeline together with the corresponding narrations provided by a voice that briefly describes what is happening. The experience lasts a total of 4 minutes and is made up of four steps. Each step is characterized by events and stimuli introduced in the VR scene to support the storyline. These elements are reported and motivated in Table 1. Moreover, these elements enable the transition between the various scenes and emotional states.

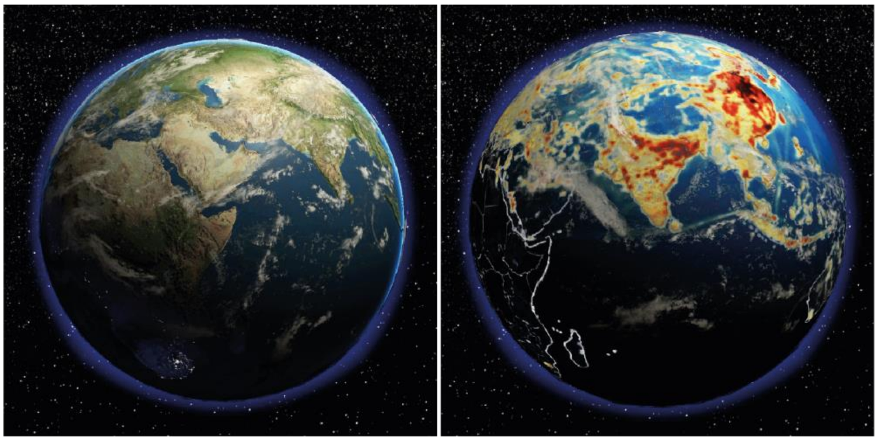

Figure 3. The space view fades in, and the user moves closer to the earth.

The desired emotions in Steps 2 and 3 are based on the guidelines by Stepanova et al. (2019). Considering steps 1 and 4, the authors use a similar strategy to the one adopted by Chirico et al. (2020): a natural familiar environment is presented to create a bond in step 1, while in step 4 a beautiful environment is spoiled by human actions, aiming at increasing the awareness of damage. In fact, while the main guidelines used focus on the overview effects, additional ones for the design of VR environments for sustainable behaviour were integrated. In Step 1 (Figure 2, right and centre images), the user is immersed in a natural scene on a lake surrounded by a forest, with typical wooden houses and Swedish flags (the case study took place in Sweden), the narrating voice invites them to have a walk. In Step 2 (Figure 2, right), the point of view moves up, the scene slowly fades into black, the voice announces that the user journey will continue far away, inviting them to be prepared, then a loud rocket sound is heard. In Step 3 (Figure 3), the space scene slowly fades in the black, the Earth appears, a heartbeat sound starts playing and the voice invites the user to come closer to the Earth. In Step 4 (Figure 4), the Earth changes showing the levels of NO2 concentration over the planet, announced by the narrating voice. The application was developed using Unity 3D.

Figure 4. The earth (left) and NO2 level displayed on top (right).

4 PILOT TEST

14 participants (4 female-10 male, mean age: 34,79 - SD = 6.6), were recruited among PhD students and researchers balancing experts in engineering design and sustainability having various backgrounds. The main aim of this pilot was to validate the application design, verifying that it was correctly experienced

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by the users according to the design guidelines. Each participant was invited to sit and answer the first part of the questionnaire (demographic data, baseline). Then, they were invited to start the VR experience using an Oculus Quest 2 and a controller. Afterwards, they answered the second part of the questionnaire. Specifically, participants were asked to rate on a 9-points Likert Scale the three dimensions of the emotion raised by each step: valence (related to pleasure), arousal (related to excitement) and dominance (related to control) according to the Self-Assessment Manikin (SAM) (Bradley and Lang, 1994). Then, they rated the intensity with which they experienced six basic emotions (happiness, sadness, anger, fear, disgust, surprise) (Ekman, 1971), plus awe, and neutrality on continuous scales from 0 to 100. Finally, the experimenter proceeded with a semi-structured interview.

4.1 SAM rates

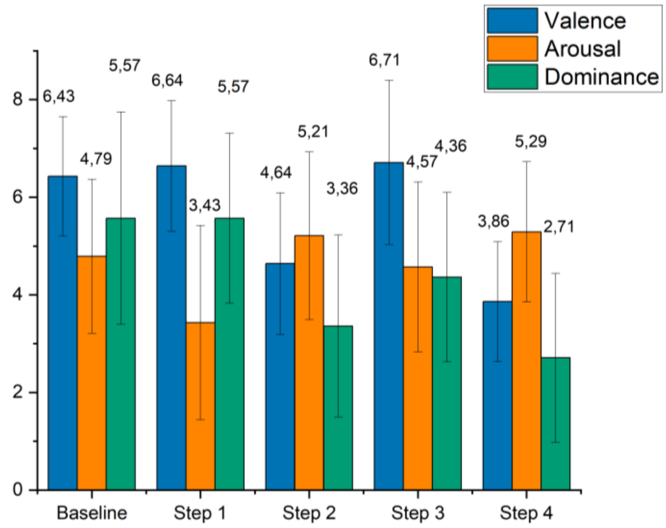

Figure 5. SAM rates for the baseline and each step.

Two normality tests (i.e., Kolmogorov–Smirnov, Shapiro-Wilk) were carried out to determine if variables were normally distributed and results show that SAM rates followed a normal distribution, therefore we proceeded with a repeated measures ANOVA. Results (Figure 5) showed a significant differences for each of the three dimensions depending on the step of the VR experience [Valence $F(4) = 15.02$; $p = < 0.001$, Arousal $F(4) = 3.75$; $p < 0.01$, and Dominance $F(4) = 7.98$; $p < 0.001$]. Post hoc analysis with a Bonferroni adjustment revealed that valence rates were statistically significantly lower ($M = 3.86$) in the Step 4 of the experience, which differed from the baseline and all the other steps excluding Step 2 ($M = 4.64$). Post hoc showed a significant difference between Step 1 and Step 2, with significantly lower arousal levels for Step 1 ($M = 3.43$). Post hoc analysis showed significant lower levels of dominance in Step 2 ($M = 3.36$) and Step 4 ($M = 2.71$) compared to the Baseline and the Step 1 ($M = 5.57$).

4.2 Emotional labels

Two normality tests (i.e., Kolmogorov–Smirnov, Shapiro-Wilk) were carried out to determine if variables were normally distributed and results show that overall data did not follow a normal distribution. We therefore decided to proceed by using non-parametric Friedman test analysis of differences among repeated measures. The results showed a statistically significant difference for each scale, except Fear rates, depending on which step of the VR experience, plus the initial baseline. More specifically:

- Happiness scale: $\chi 2(4) = 38.58$; $p < 0.001$
- Anger scale: $\chi 2(4) = 22.81$; $p < 0.001$
- Awe scale: $\chi 2(4) = 27.25$; $p < 0.001$
- Sadness scale: $\chi 2(4) = 30.57$; $p < 0.001$
- Disgust scale: $\chi 2(4) = 23.08$; $p < 0.001$
- Fear scale: $\chi 2(4) = 2.62$; $p > 0.05$
- Surprise scale: $\chi 2(4) = 10.30$; $p = 0.04$
- Neutral scale: $\chi 2(4) = 37.68$; $p < 0.001$

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Post hoc analysis with Wilcoxon signed-rank tests was conducted. Since multiple comparison increase the probability to commit Type I errors, a Bonferroni correction was applied to lowers the critical p-value depending on the number of tests performed. We had 5 conditions (including baseline) resulting in 10 (=5*4/2) possible combinations, therefore we adjusted the significance level to 0.005 (=0.05/10). Rates for each step are represented in Figure 6.

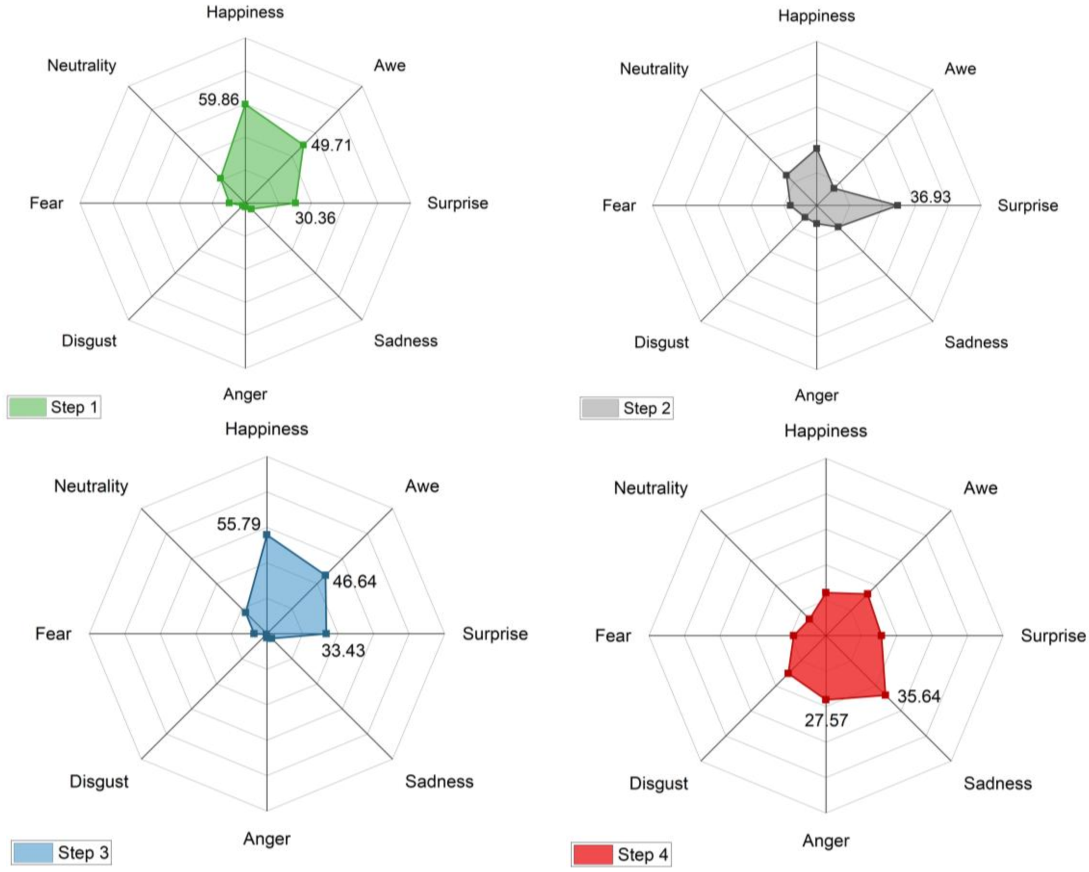

Figure 6. Emotional label rates for each step.

Happiness rates in Step 2 (M = 26) and Step 4 (M = 18.21) were lower than the other parts of the VR experience. More precisely, both Step 2 and 4 differed significantly from the Baseline (M = 61.07), Step 1 (M = 59.86), and Step 3 (M = 55.79). Anger rates in Step 4 (M = 27.14), were significantly higher than the other parts of the VR experience, except for Step 2 (M = 8.29). Awe rates were higher for Step 1 (M = 49.71), which differed significantly from the Baseline (M = 26.86), and Step 2 (M = 11.07), and for Step 3 (M = 46.64), that received significantly higher rates than Step 2. Sadness obtained the highest rates in the last part of the VR experience. More precisely, sadness rates in Step 4 (M = 35.64) were significantly higher than rates collected in the Baseline (M = 8.36), Step 1 (M = 5.14), and Step 3 (M = 3.79). Similarly, Disgust was rated higher in the final part of the VR experience (M = 22.57) and it differed significantly from the Baseline (M = 1.5), Step 1 (M = 2.21), and Step 3 (M = 0.36). Multiple comparisons for Surprise rates did not highlight differences with a significance below our Bonferroni adjusted p-value. As expected, participants reported significantly higher rates for Neutrality for the Baseline.

5 INTERVIEWS WITH DESIGN ENGINEERING AND SUSTAINABILITY EXPERTS

Semi-structured interviews with participants were conducted following the experiment to collect their opinions about:

- Their experience with the VR application, including interaction, sensory, and emotional aspects through the different steps (e.g., visual and auditory stimuli and navigation into the environment);
- The implementation of the desired requirements listed in Table 1 (e.g., how they relate to the initial scene, how the Earth appears);

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- Its potential use in academics, organizations and industries (e.g., fields, case study, context of use, possible outcomes);
- Current limitations, possible future developments, and desired features

We collected the most significant and recurrent statements identifying five main areas of concern across the perspectives listed above: visualization and representation, emotions, reflections, audience and contexts, and interaction. Participants' statements are mapped in Figure 7. Considering the general experience with the application, participants appreciated the visual aspects, and requirements of familiarity (environment in Step 1), and the Earth's attributes (Step 3) were satisfied. Interaction aspects raised some concerns due to navigation issues and the limitation of movements, making it difficult to explore the scene. The requirements considering the raised emotions appear to be satisfied, the desired surprised and reflective states were achieved, and the same can be said regarding the feeling of interconnectedness, as shown by the reflections triggered during the discussion. Participants acknowledged the opportunity to create an environment stimulating a high focus and identified potential contexts and audiences, stating that the sense of responsibility provided by the overview effect would be useful for high-level decisions as well as design and consumption choices. However, all these possible case studies require further development. In fact, future improvements and desired features include interaction possibilities, better links between visual representations and real-world effects, as well as global and local choices and consequences. The current case study was indeed designed to present a global problem, without allowing the investigation of specific causes, responsibilities, or possible solutions. Another suggestion was to make the experience multiuser and integrate follow-up experiences to enhance the application's effectiveness and improve decision-making.

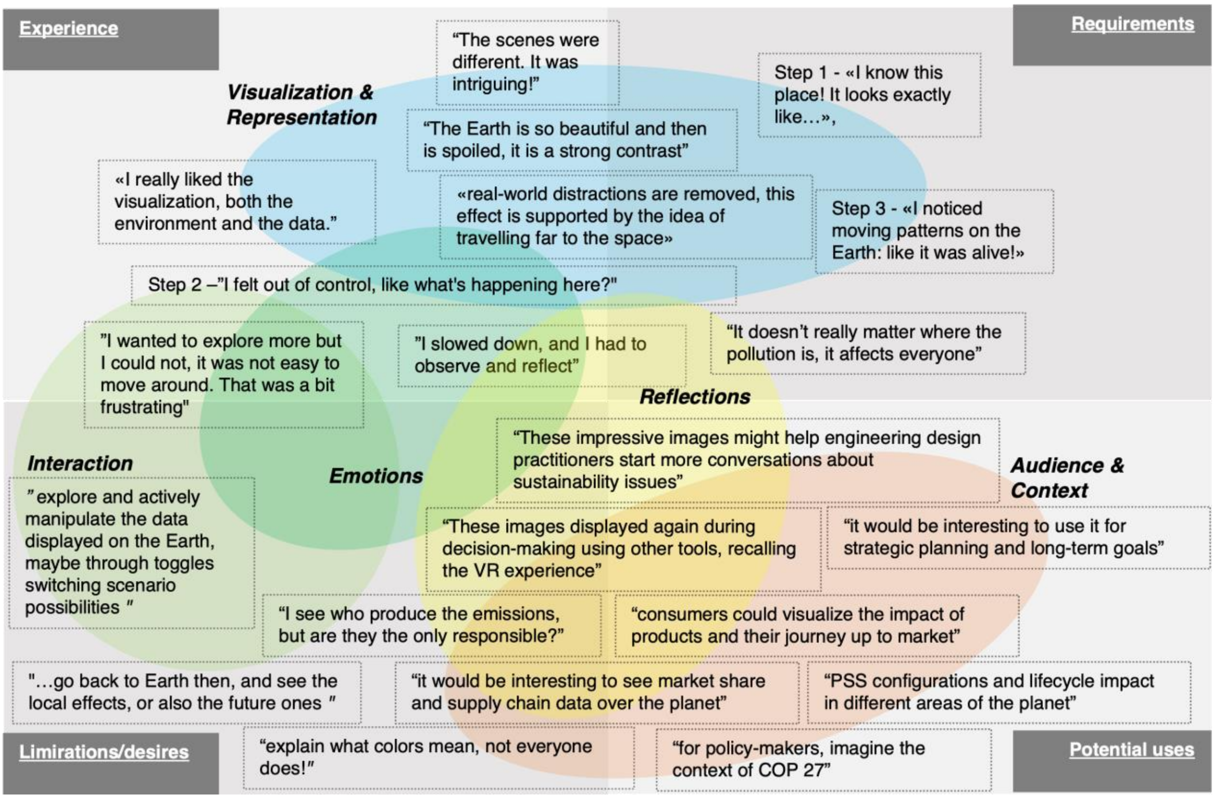

Figure 7. Participants' feedback mapped according to topic of interest and areas of concern.

6 DISCUSSION AND CONCLUSION

In this work, we presented the design and development of a VR application to support sustainable attitudes and decision-making in engineering design following the guidelines provided by Stepanova et al. (2019) and including data visualization. We evaluated the application through a pilot test with engineering design and sustainability experts, measuring its impact on emotions, and considering different steps of the experience. The study assessed the potential of the overview effect in VR to support data visualization experiences raising awareness through emotions, as a first step to

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developing future applications for decision-making in product and PSS development. The overall test results are encouraging, showing the expected effects on users' emotions for each step, with few exceptions. For instance, awe was slightly higher for the first step than for the third. However, it was the first scene participants were visualizing, and most of them had no or little experience with VR. Interviews with participants revealed more insights about the experience, highlighting valid aspects, criticalities, desired improvements, and future developments. Some of the suggestions provided by participants regard interaction, graphic, and sensory aspects that would require easy fixes, while others would be more complex to accomplish. For instance, including and relating more data into a more interactive, versatile, and agile application is not trivial. From a sustainability perspective, it is not easy to represent complexity, depict different factors, and maintain an overall view: as some participants pointed how, data should be presented to allow localizing causes and effects, preventing false connections. Finally, a challenge is to grasp and propose not only relevant sustainability-related data but also information that can effectively support and orient decision-making processes. In fact, this case study included a simple visualization of NO2 levels for design engineers' awareness, without linking them to possible strategic and operational decisions. Therefore, this work enlightened the potential of the VR experience for engineering design aspects in a limited way. A major focus and specific feedback and guidelines for this field are expected in future works. For instance, a possible future case study could integrate the experience with data visualization showing how an apparently marginal resources' saving due to a design decision could have a relevant effect when scaled up on an entire category of products across the globe (e.g., batteries for electric cars). Importantly, future activities will involve practitioners from the industry. In fact, a collaborative effort from sustainability experts, VR experts and technical experts will be required to identify and answer decision-makers' needs depending specific contexts, decisions to be made, and sustainability issues. Moreover, a variety of participants, including practitioners who are less familiar with sustainability concerns, will be involved. The design space for future development is wide, opening to several possibilities of integrating an emotional experience with current and future scenarios for the development of new solutions, adapting the VR tool to the audience. Regardless of the application field, reaching Sustainable Development Goals will require a global partnership at all levels, involving organizations and stakeholders across countries (Caiado et al., 2018). The unique sense of interconnectedness the overview effect can provide could play a crucial role.

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