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Exploring the Use of Virtual Reality to Support Environmentally Sustainable Behavior: A Framework to Design Experiences

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Abstract: The current and future challenges of sustainable development require a massive transformation of habits and behaviors in the whole society at many levels. This demands a change of perspectives, priorities, and practices that can only result from the development of more aware, informed, and instructed communities and individuals. The field of design for sustainable behavior is answering this need through the development of products, systems, and services to support the change of people's habits and decision-making processes. In this regard, Virtual Reality (VR) is a promising tool: it has already been explored to drive sustainable behavior change in several situations, through a wide range of devices, technologies, and modalities. This variety provides uncountable opportunities to designers, but it comes with a series of ethical, psychological, and technical questions. Hence, VR developers should be able to distinguish and identify possible strategies, delivering suitable solutions for each case study. In this work, we present a framework for the development of VR experiences to support sustainable behavior change, based on a systematic review. We consider the various features to manage and possible alternatives when creating a VR experience, linking them to the behavioral aspects that can be addressed according to the project's aim. The framework will provide designers with a tool to explore and orient themselves towards possible sets of optimal choices generating tailored solutions.

Keywords: sustainable behavior; virtual reality; design framework

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1. Introduction

Sustainability issues are one of our times' main concerns and include a complex set of interconnected environmental, social, and economic problems. The sustainable development goals set by the United Nations for 2030 involve these three dimensions, requiring, at the same time, a massive reduction of resources' use and their accessibility to the whole global population [1]. This radical transformation determines a need to educate citizens and professionals, increase their awareness, and ultimately support a behavior change towards more sustainable choices and consumer habits. To this purpose, Virtual Reality (VR) has been identified as a promising tool and investigated in many contexts and for a variety of topics and aims: for professionals and stakeholders [2–4], in education [5–7], and on subjects ranging from plastic pollution [8] to building design [2], sustainable mobility [9], tourism [7] and water management [6].

Moreover, different modalities have been explored, including immersive experiences [8,10], mobile applications [9,11], computer games [7,11], simulations [6,12], games [11,13,14], and single- [8,10,15] and multi-user [3,14] applications. Hence, designers creating VR experiences have a great number of possibilities available, with many potential features that can be varied and manipulated depending on the specific context. The possibility of diversifying experiences depending on the user and learning styles can be a great advantage in education [16]. Nevertheless, this potential also represents a criticality when making design decisions and orienting towards a set of choices rather than others.

Behavior change strategies are implemented in many fields, such as product design, architecture, urban planning, healthcare, marketing, and policymaking. A powerful concept is the one of nudges, interventions that alter people's decisions without coercion, leveraging their behavioral tendency [17]. For example, a possibility is to change default options, as people tend to accept defaults passively. Other approaches aim to involve people's consciousness more actively, for instance making them aware of their own behavior. An example is making resource consumption visible to users, using energy monitors [18] or everyday products themselves [19]. A strategy is to embed games into products and systems, to engage and motivate users [20]. Mentioning these possibilities, spontaneous question are: Why use a virtual space, when it is possible to change people's behavior in real life directly? What is the real advantage of using VR? As discussed in our previous work [21], VR can uniquely impact on human behavior and decision making in five ways:

- Summing behaviors' effects: displaying collective and long-term consequences
- Providing a journey in space and time
- Creating a symbolic and concrete representation
- Presenting and evaluating future solutions
- Testing future solutions with users

Moreover, these possibilities will be available for an impressive number of users. Through different modalities, every VR application can reach several people around the globe, making its potential impact extremely high. VR has been predicted to become a disruptive technology, in a way that is comparable to the Internet and smartphones [22]. However, the importance of its role in Design for Sustainable Behavior has not been fully acknowledged yet. A reason is that the design of VR experiences themselves is not trivial. The concept of VR itself is not univocal. It includes a vast range of experiences, using various graphics, different devices, involving visual or multiple sensory stimuli and requiring different actions to be accomplished by the user. In the beginning, VR has been defined on a technological basis, related to the use of devices and tools. Afterwards, it was described using the concepts of presence or telepresence: the sense of being in an environment either physically or through a communication medium [23]. In fact, VR has been defined as "the use of computers and human-computer interfaces to create the effect of a three-dimensional world containing interactive objects with a strong sense of three-dimensional presence" [24].

Even though designing for behavior change with a focus on sustainability targets is a matter of interest for many industries and organizations, designers currently lack education and tools to do it [25]. Specifically, when it comes to VR, there is a lack of guidelines, tools, and models that designers can use to create compelling VR experiences. This work aims to identify design features for VR experiences and provide designers with an overall view of the strategies to support sustainable behavior, proposing general directions and patterns to follow and representing them in a visual framework. The paper is structured as follows. we discuss related work in Section 2. The protocol of the systematic review on which the framework is based is described in Section 3. Behavioral aspects are discussed in Section 4, while framework elements and categories are discussed in Section 5. In each subsection, a framework element is discussed: for each one, we identify possible alternative categories and describe them, reflecting on their objectives and potentials. In Section 6, we relate the categories previously found to behavioral aspects in the framework, which includes and links the factors that designers can manipulate to the possible strategies to target human behavior. In Section 7, we discuss how the diffusion of VR applications can impact the design of sustainable solutions.

2. Related Work

Frameworks can be used to design and assess physical and digital artifacts: different elements (e.g., design features, practices, and methods) can be visually organized and related in a way that can have an explicatory or orienting value. Blizzard and Klotz presented a framework for sustainable whole systems design, based on a systematic review, relating design processes, principles, and methods [26]. Withanage et al. presented a framework to design for sustainable behavior focusing on the use of appliances, describing steps to identify and categorize design opportunities and interventions, based on the observation of users' behavior [27]. An integration of frameworks to design for sustainable behavior was proposed by De Medeiros et al. [28], identifying analogies and complementary aspects. Among the mentioned frameworks, an example is the one presented by Tang and Bahmra, who related different phases in behavior change to a variable control of decisions that can switch from user to product [29]. These frameworks support designers in different aspects and phases, from user's analysis to implementing behavior change strategies in products. VR experiences are a different kind of intervention: while products can directly impact the behavior during their use, VR applications instead might aim to influence future behaviors. Some frameworks reported by De Medeiros et al. [28] regard features typically embedded in physical products (e.g., color, shape, and texture). The design of VR experiences requires to consider a different set of features. For instance, a series of characteristics for VR nonfictional experiences, including the viewer's role, interaction, visual and audio aspects, was identified by Bevan et al. [30]. The reflection on how to design VR experiences has been focused on the interaction between users and virtual objects, including the control assigned to users, their activity level, and the way information and feedback are provided [31,32]. A flowchart was proposed by Vergara et al. [33]. In particular, they considered the application's realism and interaction level, depending on its objective, and the hardware and software to use to satisfy these requirements. However, as the authors stated, the use of VR for specific purposes (e.g., education) would require ad hoc methodologies.

Frameworks can be designed for particular case studies. An example described by Hammady et al. regards a virtual museum guide [34]. Their framework relates usability aspects, experience factors, and contents to the guide's role and intention to use. Some frameworks concern VR experiences for behavior change, also called transformative experiences [35,36]. Stepanova et al. described the processes through which the exposure to similar environments and new knowledge support cognitive shifts, change of world views, and schema. However, these aspects are not related to specific design elements and possible alternatives [36]. A model illustrating similar mechanisms was proposed by Gaggioli et al., who discussed some design aspects concerning medium, content, form, and purpose [35]. Mitgutsch and Alvarado proposed a framework for serious games design assessment, relating the game characteristics to each other and specifically to its purpose, in a way that should be coherent [37]. The presence of an educational purpose is also a central aspect of VR experiences for sustainable behavior. For this reason, a similar approach could be beneficial. However, there is a lack of frameworks or models to support the design of VR experiences for sustainable behavior change to the present.

3. Systematic Review Methodology

To build this framework, we started by performing a systematic review of the most relevant literature in this field. The review was performed on two databases, Web of Science (WoS) and Scopus, setting the search words listed in the following. The studies were selected considering their title, abstract, or keywords, requiring a combination of at least one word from each column in the table.

We set the search words to identify the presence of VR, behavioral, and sustainability components. Concerning the word identifying the VR component, we set "Virtual Reality" and "Virtual Environment*", we combined these words to others related to human behavior to restrict the resulting studies to those using VR to support behavior change at any level.

Finally, to identify the sustainability-related scope, we included a series of words connected to the environmental dimension and issues. Search words are listed in Table 1. Search words within each column are bound by an "OR" statement. Each column is bound by an "AND" statement so that at least one word from each column is present. Search words present the asterisk to include different variants (singular and plural, nouns, and adjectives).

Table 1. Search words for the systematic review. Some search words present the asterisk to include different variants (singular and plural, nouns, and adjectives).

Search Words Related to VR	Search Words Related to Behavior	Search Words Related to Environmental Sustainability
Virtual Reality Virtual Environment *	Behavior */Behaviour * Attitude * Awareness	Sustainab * Environmental Pollution Global warming Climate change

We considered only articles and review papers in English. Then, we screened the works by reading titles and abstracts, verifying that inclusion criteria were respected. The included papers had to discuss the use of VR to support sustainable behavior, presenting case studies and solutions, reviews or perspectives on the topic. Finally, we obtained a total of 53 papers: 32 were found on the WoS, 14 on Scopus, and 7 on both databases. This number might seem small; however, it should be noted that this study is focused on behavior change to support environmental sustainability. Hence, it does not include studies that consider sustainable development goals in general, including social and economic targets [1] For instance, many works have been dedicated to improving empathy with the aim of increasing altruism and maintain human rights [38]. Moreover, VR has been used more intensively to support behavior change in different areas as for medicine and wellbeing: an example is the treatment of nutritional disorders [39]. The use of VR to support a positive behavior change for individuals, society and the planet is vast. Consequently, providing directions for the design of similar virtual environments and experiences should consider many factors. Therefore, we restricted the area to environmental sustainability, intending to provide a framework to orient designers based on previous studies' mapping.

4. Framework Behavioral Spheres

The framework shown in Figure 1 represents three behavioral dimensions through the emotional, rational, and practical spheres, which we define in the following.

Human behavior is affected by a series of internal factors, among which emotions and knowledge play two fundamental roles [40]. Emotional involvement and connection with the environment shape our values and willingness to engage in pro-environmental behavior. Knowledge includes two different areas: one regards information and comprehension of phenomena behind environmental issues, and the other concerns the action strategies to implement: both are associated with sustainable behavior. Moreover, these three dimensions affect each other: for instance, our degree of understanding of environmental issues can enhance our emotional reaction to ecological degradation [40]. Based on this reflection, we identified three spheres within designers of VR experiences for sustainable behavior change can act:

1. Emotional—related to affection, fear and connection with nature.
2. Rational—related to information and understanding of systems and phenomena.
3. Practical—related to knowhow and decision making.

The emotional sphere regards how we feel about environmental issues: VR can provide users' motivation behind sustainable behaviors by raising affection towards the environment, increasing the willingness to protect nature and avoid harmful behaviors. The rational sphere includes knowledge and understanding, shaping how we think about complex sustainability problems and their causes and consequences. The practical sphere concerns the evaluation and comparison of possible measures and solutions to face environmental issues and possible outcomes. This involves both changes in everyday life actions and choices with long-term effects.

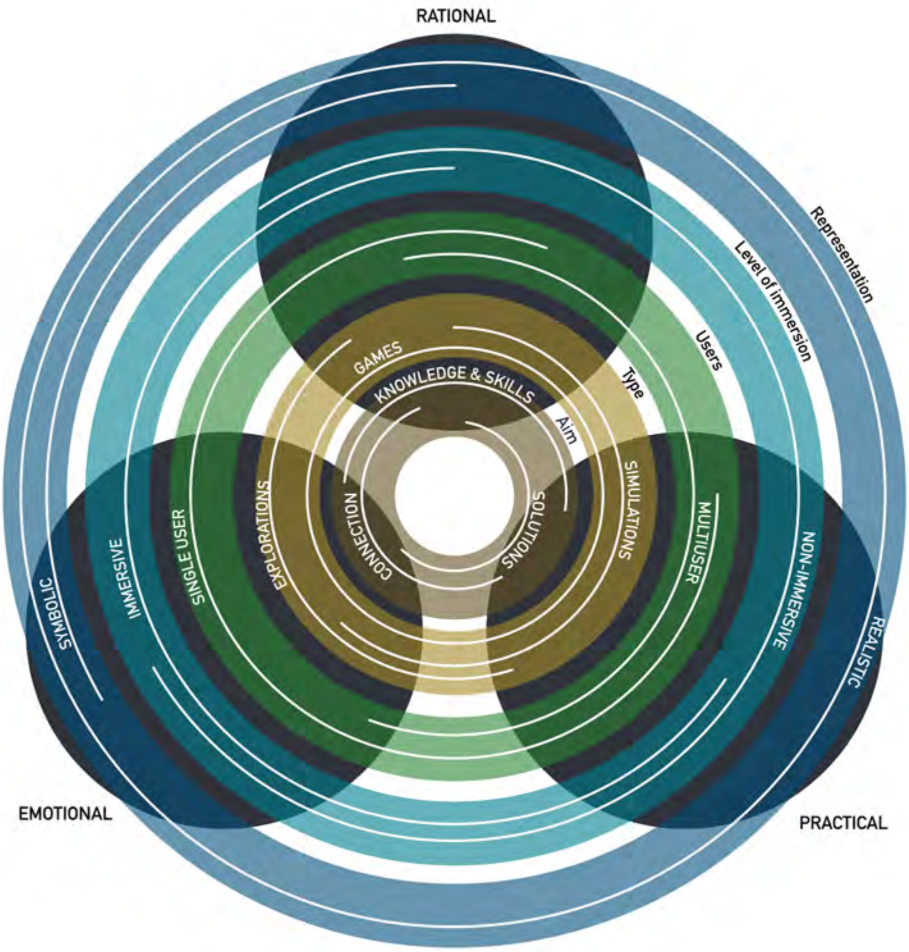

Figure 1. A framework to design VR experiences to support sustainable behaviors. The three black spheres represent rational, emotional, and practical behavioral aspects and are linked to possible variables (white lines) considering different design elements (aim, experience, users, level of immersion, and representation) represented by the colored circles.

The emotional sphere is addressed to create awareness and motivate people to adopt sustainable behavior. Potential subjects that could benefit from this strategy are, for instance, environmental organizations raising funding. However, emotions can be an additional driver to support students, citizens, and professionals' interest in sustainability related topics and pro-environmental behaviors and choices. For instance, in the behavior change model proposed by Fogg, elements of motivation have an emotional identity (e.g., hope/fear) [41].

The rational sphere is often targeted in education—primarily scientific and technical education at different levels—but can also be explored in professional contexts and in the design of products and services to improve the understanding of the consequences of actions and choices. While emotional motivation makes people feel the urgency to act, rational motivation provides a different type of support based on the awareness of complex facts and dynamics and their entity. This strategy is complementary to the former one, as the risk, mainly depicting negative scenarios and predictions without a scientific explanation, is to make people skeptical [42].

While strategies belonging to the emotional sphere motivate users, the rational sphere aims at informing them. Finally, the practical sphere enables them to concretize more sustainable behaviors and choices. It interests practitioners and future ones, as well as citizens in their everyday life as users and consumers. Specifically, it reveals how powerful a change in habits or decision making can be. People might be informed and motivated but lack knowledge on how to implement changes or the awareness of their ability and actions effectiveness. Self-efficacy and perceived control deeply affect sustainable behavior and choices, considering citizens/consumers and professionals [43,44].

5. Framework Elements and Categories

Colored areas in Figure 1 represent design elements. The white lines represent the categories for each element, depicting their presence and relevance considering the behavioral spheres. VR experiences for sustainable behavior are designed with a specific educational purpose, such as serious games [37]; in fact, the element we see in the center of Figure 1 is the aim of the experience. Then, we describe design elements: the type of experience, number of users, level of immersion, and type of representation. These elements were identified and analyzed through the review we present, verifying the distribution of works in different categories. These elements do not cover all the possible design aspects, but they were identified as affecting fundamental design decisions and are deeply correlated. For instance, the type of experience may be affected by the kind of device or technology chosen, which determines the level of immersion. Moreover, the type of experience is related to the number of users, also playing a role in the device's choice, as the interaction between users becomes a fundamental aspect.

Here, we describe the different elements found in the framework, the various categories for each element, and their distribution according to the literature review. Each work can fall into more than one category.

5.1. Aim of the VR Experience

VR has been explored as a tool to target different aims related to sustainability. VR experiences and applications can be developed to target various factors that affect people's behavior towards the environment. Those include:

1. Environmental connection: Affection and responsibility towards nature
2. Knowledge and skills: Awareness of how human behavior impact on the environment;
3. Testing and presenting solutions: Understanding of the effects of decisions

Twenty-four (45.3%) of the reviewed works aim at creating an environmental connection, 23 (43.4%) at providing knowledge and skills, and 14 (26.4%) at testing or presenting solutions (Figure 2). In Figure 2 (right), it is possible to observe the distribution of each target in three different behavioral dimensions previously described that can be found in the framework (Figure 1).

Environmental connection is one of the primary needs for many people who lack occasions and time to contact nature, which is one reason people are not sensitive to environmental issues [10,45]. Hence, real experiences are being increasingly replaced with virtual ones [46]. For instance, Fletcher et al. discussed how games on tropical rainforest conservation could increase affective commitment, even more than direct experiences [11]. In this case, the goal was to address people's emotions, stimulating their willingness to take care of the environment. Virtual experiences can make people feel closer to the environment, perceiving higher risks related to its pollution [13]. Users can also embody animals affected or endangered by environmental issues, experiencing and feeling their situation [47]. It is also possible to make people accomplishing pro- or anti-environmental actions, such as cutting down or growing a tree, experiencing a sense of direct responsibility [48]. Moreover, VR allows both to create a sense of connection with nature in remote areas—such as the oceans [5] or arctic regions [49]—and to promote local natural sites, increasing local communities awareness [50]. In this regard, while, according to Sheppard [42], familiar virtual landscapes raise more affection, Ballouard et al. found that children tend to protect more exotic nature [51].

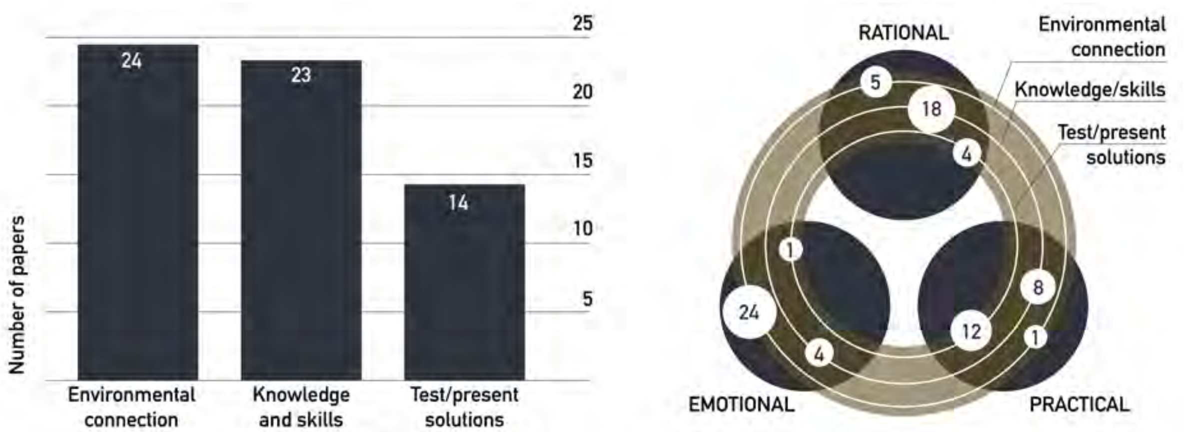

Figure 2. (**left**) The distribution of works considering the aim of VR experiences; and (**right**) the distribution of works according to the aim in three different behavioral dimensions.

Interventions to provide knowledge and skills support awareness of the ways human activities affect the environment and how this can be improved or avoided. People may have environmental values but lack the information to engage in pro-environmental behaviors and make sustainable choices in their everyday life (e.g., consumption behavior). This occurs as people do not have a clear view of the cause–effect correlations—the connection between their behavior as a citizen or consumer and the sum of multiple similar society behaviors over time. For instance, Chirico et al. used VR to show users their plastic bottles consumption as a single citizen and as a community, over different time spans [8]. This approach is also used in education, as VR experiences can increase theoretical and procedural learning [15] and support the understanding of complex social, economic, and environmental issues such as water management in agriculture [6]. This strategy also applies to professional contexts: operators can be trained to achieve safety, profitability, and sustainability targets [52] and stakeholders can increase their understanding and awareness and improve their decision-making skills [53,54].

Furthermore, the third aim regards decisions having a long-term impact, such as complex activities involving multiple professionals and stakeholders (e.g., management or design decisions). The aim is one of presenting and testing solutions. In this case, the VR experience should provide an understanding of the consequences of a choice, supporting comparison and evaluation processes. An example was described by Hamilton et al., proposing a VR system integrated with geographical information for urban planning [55]. Resource management is another potential activity to target since it can involve multiple stakeholders and population groups with different interests and contrasting environmental, social, and economic targets. For instance, water management can be problematic: Larson et al. discussed how visualization could support the development of a collective vision among stakeholders comparing alternatives [3]. Designers, architects, and engineers can also compare different solutions, for instance disassembly configurations [56] or building design, forecasting and evaluating their environmental impact, including behavioral factors (occupants profile and consumption) [57]. They can also test how a design impacts users' behavior [12] or perception [58], understanding which solution leads to more sustainable actions or decisions.

5.2. *Types of VR Experience*

The type of VR experience can vary depending on the aim, target users, context, and technologies. These VR experiences could be:

1. Explorations: Raising awareness through emotional involvement
2. Games: Raising interest and providing knowledge through engagement
3. Simulations: Providing understanding through making predictions and testing solutions

Twenty-six (49%) of the reviewed works fall into the category of "explorations", 19 (35.8%) fall into the category of "simulations", 8 (15%) can be categorized as "games", and 2 are identified as "various/non-specific" (Figure 3). The number of VR games seems small, which might be due to the search words used. Works presenting serious games might not mention VR, even when the games discussed are played in a VR environment. In Figure 3 (right), it is possible to observe the distribution of each typology in three different behavioral dimensions.

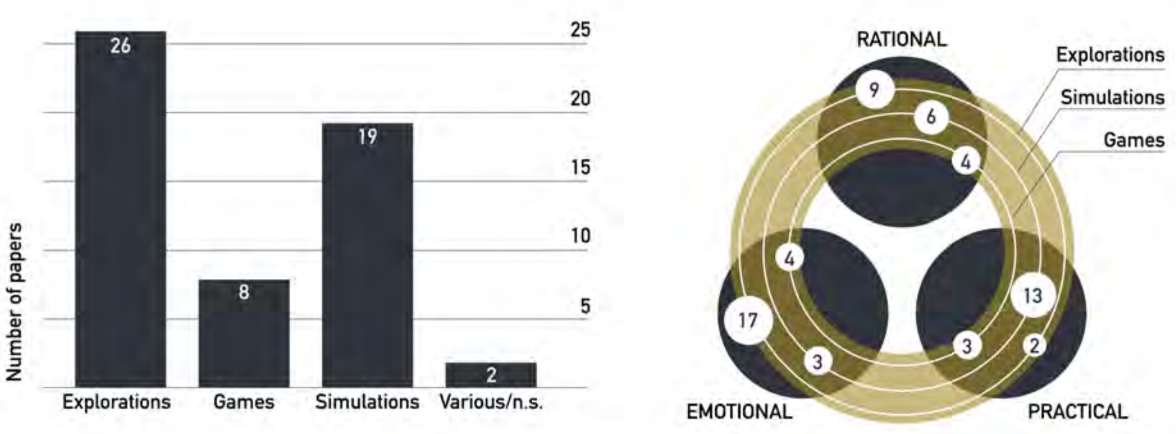

Figure 3. (**left**) The distribution of works considering the type of VR experience; and (**right**) the distribution of works according to type of experience in three different behavioral dimensions.

Considering exploration experiences, VR allows shortening physical, temporal, and, thus, emotional distances [10]. Users can be immersed in contexts and observe phenomena located far away in space and time, making remote areas accessible. For instance, they can see the current and future impact of climate change and pollution on seabeds and oceans [59] or on arctic regions [49]. As shown in Figure 4, exploration experiences can focus on loss, when users visualize the negative impact of human behavior, or gain, when they can appreciate the natural environment. However, according to Klein and Hilbig, a mere experience with nature, if not associated with other concepts (e.g., the need for conservation), is insufficient to promote pro-environmental behavior [60]. This is consistent with the results of Soliman et al. [45], who described an example of a positive immersive journey in nature. An example of a negative one, displaying the consequences of ocean acidification, was proposed by Markowitz et al. [5]. These strategies aim to create a sense of responsibility by feeling the urge to change a harmful behavior, or instead understand the value of natural resources and enhance the willingness to preserve them. A comparison of these two strategies was proposed by Ahn et al., exposing users to a tree cutting or a tree growing experience to change their intentions of paper consumption [48], finding the positive one to be more effective. Differently, Nelson et al. compared the description of coral reefs importance and benefits to the risks associated with their loss and found negative messages displayed in a 360° video to be more effective [61]. Exploration experiences are often passive when users are guided through the virtual environment: Breves et al. proposed to expose users to 360° videos of natural environments [10]. The simple exposure to a narrative can be effective when the objective is to provide an impressive experience [8,61]. For their emotional impact, these experiences can be used for education [5], fundraising [61], and also in advertising to improve the future experience with products [62].

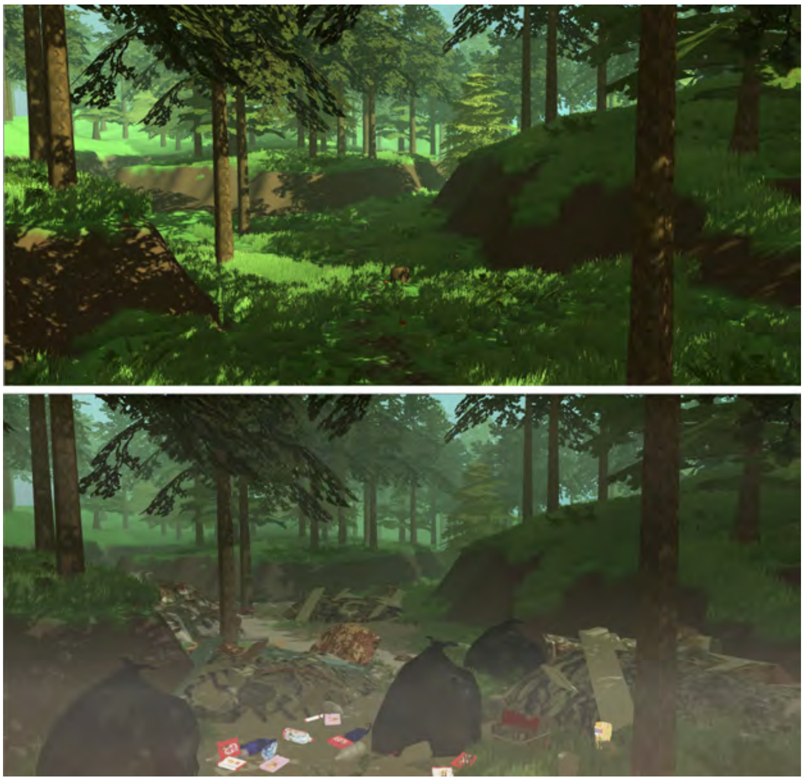

Figure 4. An example of positive experience (**top** image) and negative experience of loss (**bottom** image) in a forest. The virtual scenes were created by the authors.

However, Ahn et al. [48] compared passive and active experiences for users, finding the high interactivity condition more effective. Highly interactive experiences such as **games** involve users in a series of activities and actions having a positive impact, supporting self-efficacy [13]. Players usually interact with virtual objects to various extents, affecting responses and events in the environment. A simple interaction can be integrated into the VR environment by proposing quizzes to engage users and verify learning [63]. Instead, in more complex games, users receive feedback on how their decisions affect the gaming scene [15]. Players' actions can affect the environment and other people (e.g., a population of non-players) [64]. In similar games, flow and immersion can increase learning [15], which is why serious games are used in both educational [13,65] and professional contexts [66,67]. Serious games simplify complex concepts, systems, and dynamics: this can be useful considering the complex challenges of sustainable development. For instance, in the game developed by Wang et al., users need to balance economic growth and the rise of environmental temperatures [15].

Finally, simulations aim to use knowledge to predict future conditions and experiment with possible solutions, present, discuss them, and eventually test them. For these reasons, they are the most diffused typology in professional contexts and the one that is more oriented to practical goals. Simulations rendered as VR experiences can be used to make and compare predictions considering the impact of a decision: Su et al. [57] presented a system to visualize dynamic Life Cycle Assessment (LCA) of buildings depending on their design as well as mutable factors. Stakeholders and practitioners can use simulations to support management decisions on land use [4] and urban planning [55] or optimize industrial processes [56]. However, simulations are also used in education as demonstrations of complex systems and dynamics, increasing learning and understanding, such as in natural resource management [6] and low energy buildings in architecture [68]. Simulations can also be used as tools to gain an understanding of participants' environmental values and behavior, proposing them possible real-life situations and recording their choices [69]. Simulations also usually involve a certain level of interaction, as users can manipulate some parameters and visualize the effects. For instance, Kirilenko et al. proposed a tool that landowners can use to provide information about vegetation in their forest and apply different management techniques, predicting the effects in some decades [4]. In addition, simulations that are performed to investigate human behavior [69] or to test the impact of products and environments design on consumptions [12], certainly need interaction.

5.3. Level of Immersion, Devices, and Stimuli

VR experiences can be immersive, using Head-Mounted Displays (HMDs), large stereoscopic wall, and CAVE systems, or non-immersive, using 2D PC screens or smart devices, including tablets and smartphones. Twenty-three (43.4%) reviewed works are classified as non-immersive, while 22 (41.5%) are considered immersive. The remaining eight (15.1%) works regard both (Figure 5). In Figure 5 (right), it is possible to observe the distribution of works considering the level of immersions in three different behavioral dimensions.

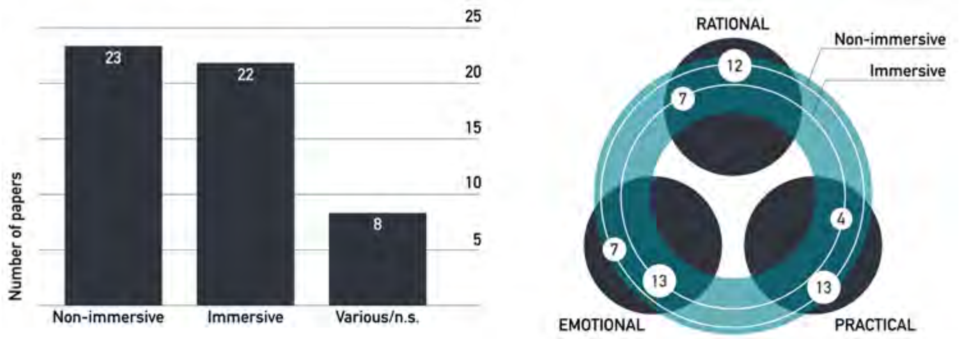

Figure 5. (**left**) The distribution of works considering the level of immersion; and (**right**) the distribution of works according to the level of immersion in three different behavioral dimensions.

Most VR applications are essentially visual. However, the experience can be enriched by other sensory interactions, such as haptic feedback and olfactory stimuli. For instance, Tagliabue et al. used VR to test the effect of visual and olfactory cues to affect thermal comfort for energy conservation [58]. The choice of the level of immersion and device may depend on different factors related to the context, aim, and type of experience to provide. The possibility to use multisensory stimuli allows both proposing a variety of experiences and testing a variety of solutions. Figure 6 shows different devices that can be used for immersive and non-immersive VR, including multisensory applications.

When raising emotional responses is a priority, generating a high sense of presence (that is, the feeling of being present in the virtual environment), the level of immersion can be a decisive factor [10,45]. In this regard, Filter et al. found immersive experiences to be more effective, raising interest even in people without a positive attitude towards an environmental issue [70]. HMDs and, even more, CAVE technologies can provide a higher sense of presence and emotional arousal compared to desktop displays [71]; however, they are not always an optimal choice.

When it is fundamental to reach a significant number of people, which is the objective of many environmental organizations, choosing widespread devices can be a better option [11]. When designing a VR experience, it is fundamental to consider how it will be delivered since the final impact is a matter of effectiveness and availability. The context is essential when selecting the device and tools to use. Greater accessibility can lead professionals to prefer more traditional media, even when VR experiences are more effective [53]. For similar reasons, a high level of immersion is challenging to manage when there is the need to engage multiple users simultaneously (as the use of HMDs limits the interaction with other people). It is also problematic when suitable spaces are not available due to safety issues (since users cannot see the surrounding environment). Another factor to consider is the duration of the VR experience, since HMDs might cause discomfort, and VR sickness negatively affects the user experience [72].

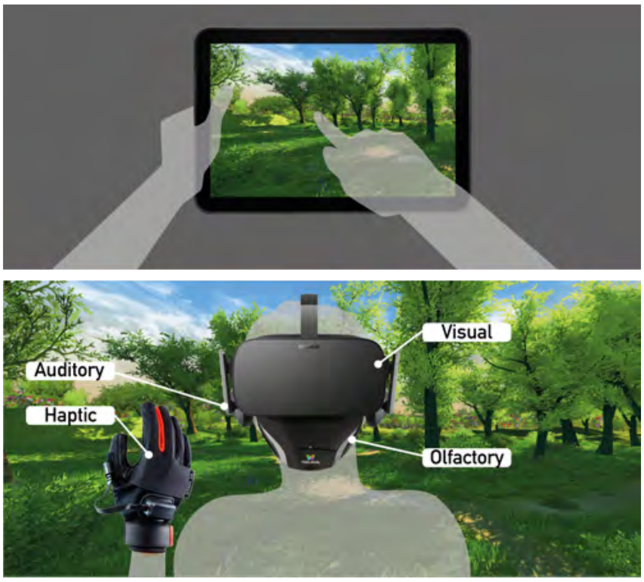

Figure 6. (**top**) The user interacts with the VR scene through a tablet; and (**bottom**) the user is immersed in the scene and provided with visual, auditory, haptic, and olfactory devices. The virtual scenes were created by the authors.

5.4. Single- and Multiuser Applications

VR experiences can be designed for one or more users, focusing on personal aspects or social dimensions. This also depends on the aim and type of experience to provide, which can involve developing personal values, instead of supporting competitive dynamics or collaborative tasks. It also depends on the context: it can be individual or collective, recreational, professional, or educational. Immersive environments are usually designed for single users [8,10,45], raise awareness and emotional responses, and focus on the connection between self and nature. It is not easy to communicate with other people in similar settings, while there can be a more robust interaction with virtual characters. Instead, it is easier to involve multiple users through computer-based experiences, such as the multiuser learning environment discussed by Fokides et al. [59], or mobile applications, such as the one proposed by Roider et al. for sustainable mobility [9]. Games can involve single or multiple users at the same time [11]. In contrast, professionals and stakeholders involved in complex decisions, e.g., policy-making and management of natural resources, need collaborative environments [73]. Moreover, a multiuser environment can stimulate social factors to achieve behavior change through dynamics as competition and praise [9].

Sixteen (30.2%) reviewed works describe multiuser applications, while 33 (62.3%) regard single-user applications. The remaining four (7.5%) works consider both (Figure 7). In Figure 7 (right), it is possible to observe the distribution of multiuser and single-user works in three different behavioral dimensions.

5.5. Realism or Symbolic Representations

VR representation can be realistic, faithfully depicting phenomena and environments, or using graphic styles, symbols, and representative objects to explain and clarify concepts and facts. The choice of graphic quality and style depends on the kind of experience and its aim. For instance, explorations to create environmental connections are usually realistic and detailed, picturing a natural environment's beauty or degradation. In Figure 8, two types of representation of urban air pollution are compared. Figure 8 (top) is more faithful to a real-world scene, raising users' awareness. Figure 8 (bottom) presents countable objects that could make it easier to compare different scenarios or understand the entity of feedback to a specific action. This choice could be optimal in games that often alter and exaggerate the representation of phenomena, including feedback to human actions and the perception of their consequences, to surprise and engage users [74]. Moreover, in games, the correlation between users' actions and effect on the environment is not realistic, but somewhat simplified, accelerated or metaphorical (e.g., the player's action harm the environment and a tree disappears to represent the damage) [15,64,74]. This feature can be useful in a simulation when it can be advantageous to use different representation formats and graphics that are easier to understand. It is possible to concretize abstract information, for instance, representing the energy wasted by heating water using pieces of coals [75]. However, if the aim is to test a design choice to evaluate the interaction users would have in reality [12], a realistic approach can be more suitable. A realistic experience is also essential when VR journeys are designed to avoid or reduce real-world traveling, as a more sustainable, cheaper, and safer alternative for education, leisure, or working purposes [7,76]. VR allows comparing different representation formats: Chirico et al. implemented three different designs of a simulation, showing the user's consumption of plastic using numbers, the correspondent number of water bottle models, or a combination of both [8] displayed in a garden. In this case, the graphic representation is realistic; however, the presence of a similar quantity of plastic bottles in this natural environment is not a real phenomenon.

Forty-four (81.1%) reviewed works describe realistic experiences, while nine (17%) regard single symbolic representations (Figure 9). In Figure 9 (right), it is possible to observe the distribution of works using symbolic and realistic representations in the behavioral dimensions that can be found in the framework (Figure 1).

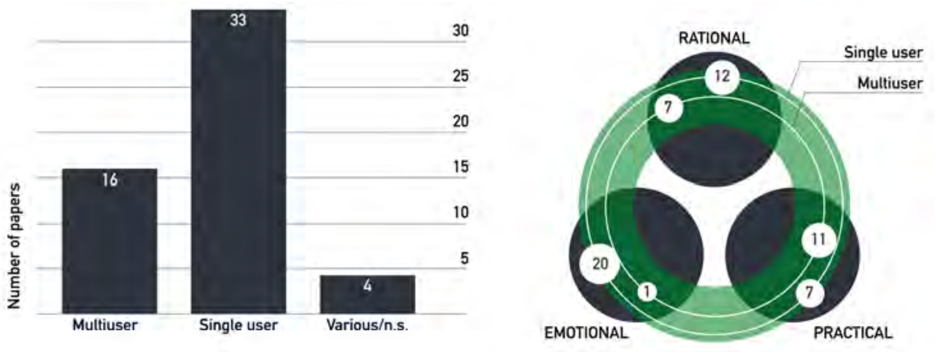

Figure 7. (**left**) The distribution of works considering the number of users; and (**right**) the distribution of works according to the number of users in three different behavioral dimensions.

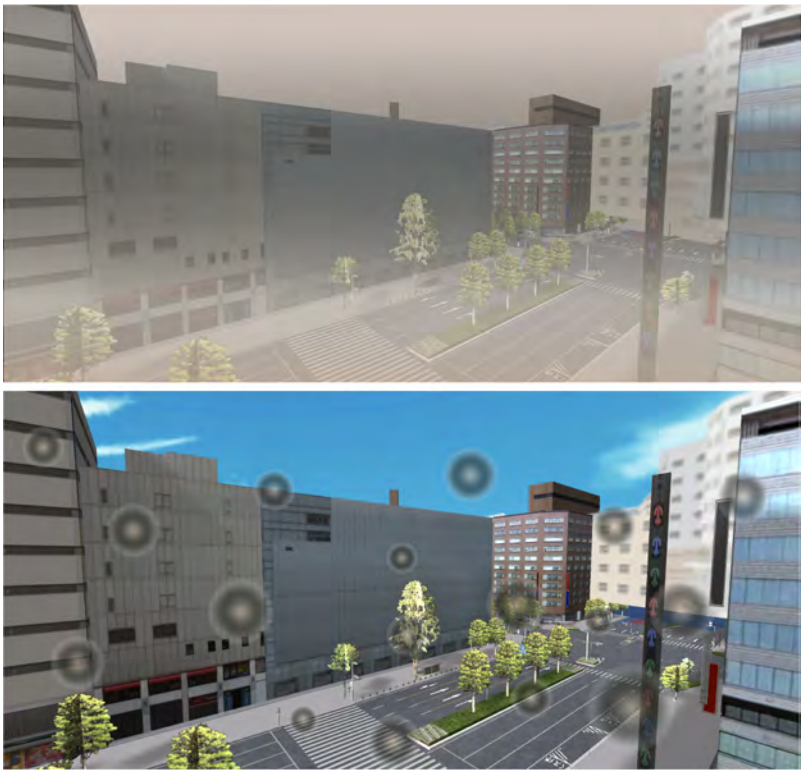

Figure 8. An example of realistic representation (**top**); and an example of symbolic representation (**bottom**) of air pollution in a town. The virtual scenes were created by the authors.

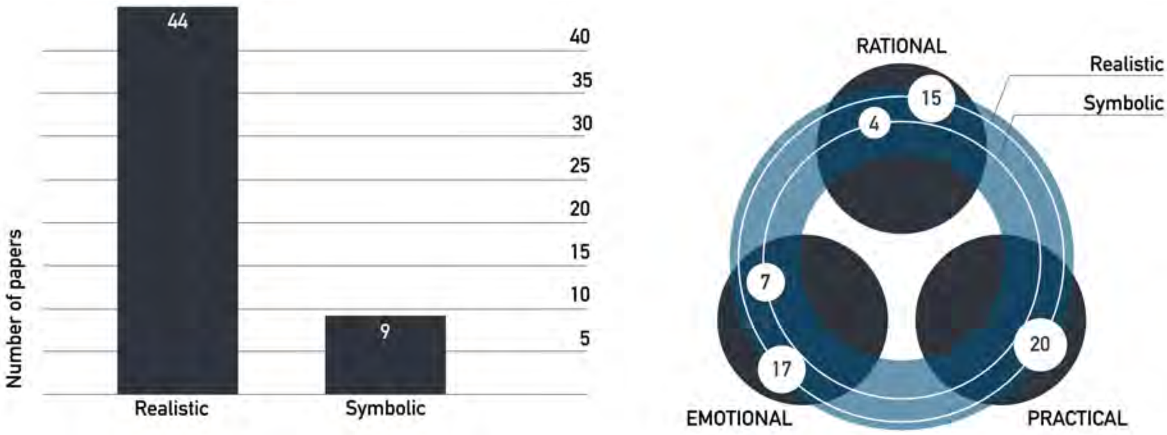

Figure 9. (**left**) The distribution of works considering the type of representation; and (**right**) the distribution of works according to the type of representation in three different behavioral dimensions.

6. The Framework as a Tool to Orient the Design of VR Experiences Considering Behavioral Dimensions

As shown in Figure 1 and described in Section 4, the aim of VR experiences is related to three behavioral dimensions or spheres: emotional, rational, and practical. The framework includes the representations of each element and categories described and illustrated in Figures 2, 3, 5, 7 and 8. Each work can be included in more than one sphere in the framework (e.g., both emotional and rational spheres) and more than one category (e.g., the aim is to create a connection and, simultaneously, provide knowledge and skills). Not surprisingly, the aim of the application is strongly related to the sphere: there is a dominance of works aiming at creating a connection with the environment in the emotional sphere, providing knowledge and skills in the rational sphere, and presenting and testing solutions in the practical one.

Considering the kind of experience, in the emotional sphere explorations of remote places and times, appreciating natural heritage and experiencing its loss [5,8,45] are the most diffused type. However, VR explorations also are the most common type in the rational sphere: they do not only raise emotions but also allow users to visualize and comprehend complex phenomena such as climate change or ocean acidification [5]. Games can be used in all three spheres: to get people to feel closer to the natural environment [11], but also in the rational and practical spheres, to support learning [59] and enhance decision-making skills [14]. However, the number of games rendered by our search is quite small, as discussed above. Many VR simulations are related to the practical dimension. Professionals and stakeholders can compare and discuss design and management alternatives [4,12,73], as well as predict how they will affect future behaviors (e.g., users' behavior) [58]. This awareness empowers users to make conscious choices and find solutions. However, simulations can be found in the emotional sphere, especially when adopting specific representation formats, involving symbolic visualizations or actions [8,74,75].

The number of users and level of immersion appears to be correlated. Single user applications are the most diffused in the emotional and rational spheres, representing almost the works' totality considering the former. In fact, works in the emotional sphere target individuals' feelings and motivation. A high level of immersion increases the sense of presence and, consequently, the connection with the environment [8,47]. While the emotional field is personal, the practical one often requires users to collaborate, moving the major interaction from the virtual environment to real space. Professionals or stakeholders can compare and discuss together the different solutions presented. Hence, a multiuser and non-immersive experience is often preferred [53,73]. Nevertheless, if the application aims to test the way users behave using products, buildings, or services, immersive solutions can be ideal. In fact, the user is immersed in a condition that resembles the one in the real-world [12,58]. In the rational sphere, both approaches can be found, probably because, even though they address individual knowledge, applications to support learning are often multiuser, since learning activities are conducted in a social context [14,59]. Finally, regarding the type of representation, VR realistic experiences are widespread in all spheres. Considering the emotional one, they have great potential when combined with a high level of immersion, making users feel contact with nature. In this case, VR is often used to replace real trips, so a realistic and accurate visualization is optimal. Realistic experiences are also common in the rational and practical spheres. Depicting reality can provide credibility in the former case, while, in the latter, it is necessary for a correct evaluation and assessment of a given solution. Symbolic representations are not trivial to implement; hence, they are rare. They can be used to impress users and raise emotional responses [8,74]. However, they can also be found in the rational sphere since they can be easier to interpret and elaborate, increasing users' ability to quantify and evaluate an event's entity or the consequences of an action [75]. In the practical sphere, they are not present, probably because there is a significant focus on representing solutions and real situations, even though they might be useful to support decision making by increasing the understanding of information. The framework shown in Figure 1 can provide designers of VR experiences with a view of the possible way to use VR, starting from the aim of their application and considering the various aspects to manage, depending on the behavioral sphere within they want to act. This can be useful at the beginning of the design activity to have an overall picture of the VR potential and orient towards the most suitable strategy, also considering that different features and objectives can be combined. The framework can also be used to visualize current gaps that might be explored. This will support the development of VR experiences to raise awareness, educate and instruct citizens, consumers, professionals, and future ones. This framework's potential is also related to its possible impact on further design activities, amplifying the effects of VR applications on professionals and citizens in the ideation and use of sustainable solutions.

7. How VR Applications Will Impact the Design of Sustainable Solutions

The framework aims at orienting the design of VR tools, facilitating a more aware and specific development of similar applications, increasing their effectiveness and diffusion. A context that will be affected by this phenomenon is one of design and engineering activities. This field is particularly relevant due to the multiple and intercorrelated effects that can be triggered to achieve sustainability, involving both professionals' decision making and users' future behavior. The use of VR experiences to support design activities can be related to practical spheres. However, designed solutions, displayed and tested in VR, can explore strategies that also involve the rational and emotional ones. For instance, in the field of architecture, VR can be used to evaluate the building design and its environmental impact, as well as considering users behavior [12], or to educate future designers to do so [68]. However, the use of VR applications to support designers and engineers can be expanded.

As an example, they can support immersion when conducting product development and design thinking projects. They can 'plunge' the team in the design situation and explore solution scenarios standing in the 'shoes of the customer'. This can improve the team's capability to evaluate the more intangible aspects of value creation already in the preliminary design phase. Noticeably, this will make it possible for designers to virtually experience the benefits and drawbacks of a concept with a look at how this will trigger sustainable behaviors among customers and consumers. Methods and tools for customer journey mapping, for instance, can be enriched by the use of VR. Designers can immerse themselves in the typical day in the customer's life to have a hands-on experience of how he/she will be prompted to behave (or not behave) sustainably when interacting with the solution. Recent reports [77] even foresee the emergence of a new role in the organization, that of the Extreme Virtual Tester (EVT). The EVT will have a computing and gaming background and will exploit the virtual realm to explore a products' behavior from a usage perspective, identify weaknesses of emerging products, and inform the quality teams. Similarly, Visual prototype designers are expected to quickly create visual models and try out new ideas in a virtual or augmented world. In this respect, VR techniques will raise understanding of the most implicit and emotional impact of products, making it possible to analyze motivators, drivers, and attitudes towards sustainable behavior.

Undoubtedly, a significant aspect of product design is manufacturability. VR is already proposed today to support the Real-Time (RT) optimization of manufacturing processes and equipment [78], but also, in the perspective of circular economy, to improve disassembly processes [56]. An advantage of using VR technologies in conjunction with process simulations (e.g., discrete events) lies in the opportunity to navigate manufacturing processes (and delivery and supply processes) already during the early stages of product design. This will be used to raise awareness about possible bottlenecks or the consequences of the system failures and the more intangible concepts of cleaner production through the interactive visualization of waste, CO_2 production, water consumption, and more. Indirectly, immersion will also improve communication and knowledge sharing in the cross-functional team during design review. More people will be able to grasp the simulation model's meaning and results, suggest improvements, and actively contribute to fine-tuning manufacturing processes from a performance perspective and a sustainability viewpoint.

Furthermore, Product-Service Systems (PSS) are advocated by many to be a significant leap forward from a sustainability viewpoint. However, while the PSS concept holds plenty of potential, successful industrial implementations are rare. This is because it is difficult to fine-tune the design requirements for the PSS: a reason is found in how the PSS is intended to create value, which is through ownerless consumption. The psychological boundary linked to the latter is a significant hindrance to the mainstream application of PSS in the consumer markets. In the future, the development of a virtual environment where the PSS can be experienced from a customer perspective and not only represented through service blueprint as it happens today will be a game-changer from the point of view of raising the success of these initiatives. Immersion will make it possible to assess the most intangible, subjective aspects of PSS during the design phase, fine-tuning hardware, software, and services for success.

VR technologies can also enhance virtual testing capabilities, shifting the focus from the analysis of pure performances to assessing the entire product experience, from conception to disposal. This will raise awareness on those aspects of the lifecycle with substantial sustainability implications. Modeling and simulation are becoming common throughout the development process, enabling companies to simulate individual-use cases and product life cycles. With rising computer power and simulations becoming instantaneous, it will be possible for future designers to require an instant response from their tools and techniques, evaluating new concepts rapidly. Noticeably, when testing options, engineers will not only focus on the behavior of the product but also on its ability to fulfill the sustainable development goals. Moreover, it is crucial to notice that there is today an apparent movement towards gamification in the engineering design practice [79]. VR will play a fundamental role in the gamification transformation, inevitably impacting how products and systems are developed from a sustainability viewpoint.

Noticeably, the ability to develop solutions triggering sustainable behaviors is strongly limited today by the need to raise communication and collaboration in cross-functional teams. The engineering practice in the future will need to become more systemic, interdisciplinary, and virtual in which new groups of people will have to work together, involving more people than ever before (often in different cities, countries, and continents), exploiting their unique knowledge. VR techniques—by making it possible for these individuals to communicate and exchange their knowledge seamlessly—will represent a leap forward in how sustainability factors are discussed in the engineering design process, in conjunction with the more classical cost and quality requirements.

8. Conclusions

The current global situation is characterized by severe environmental risks and aims to achieve ambitious sustainability goals. It demands a radical change in people's behavior at different levels in society. Citizens, consumers, professionals, and educators need to be informed, motivated, and empowered to concretize this change. People's motivation is affected by their experiences in life that influence their attitudes towards the environment and, in general, their sensitivity towards sustainability issues.

Nowadays, we spend more and more time in virtual environments [80]. Moreover, recent events related to the COVID-19 pandemic emphasized this condition. While this could distance us from experiencing nature, this disadvantage could be reversed and empowered, making natural environments and knowledge more accessible and available at any moment and for different target groups. This also required many professionals in the industry and in the academics around the world to change the way they work, interact, and collaborate, introducing new difficulties and needs and sometimes exacerbating pre-existing ones. VR can be a tool to overcome these obstacles, also offering some advantages compared to real-life experiences. For instance, it could make the experience itself more sustainable, as in field trips for environmental education, or it can be useful to track and analyze users' interaction and activities or enrich the experience with additional and more understandable information. In this work, we describe how this can be applied to different contexts, presenting a review and mapping of works and a framework to orient designers in the concept and development of VR experiences. Finally, we discuss the potential impact of VR applications.

VR technologies and environments have great potential in addressing sustainable behaviors and attitudes in several situations and considering various topics and objectives. It is possible to use VR in education and professional contexts. VR can also be suitable for the general public to enhance people's interest and knowledge for environmental issues and to support sustainable behavior change. It is possible to deliver an extensive range of experiences by manipulating graphical features, including sensory stimuli, involving different users, and choosing multiple devices. This variety leaves designers with uncountable possibilities, requiring them to make several design choices, which combined will deliver a specific experience that should be tailored for each case study.

We defined a series of factors and features that can be varied and arranged to design a VR experience, distinguishing a set of alternatives. Then, we mapped them in a framework considering three behavioral spheres corresponding to emotional, rational, and practical aspects.

The framework will be a support tool for designers to explore and overview the different dimensions to consider for their VR experience depending on their scope. This representation includes the main design elements, stimulating VR developers to view them simultaneously and reflect on possible correlations between them. Elements positioning in the framework is not casual: the aim is considered the central element to clarify, followed by the type of experience, allowing designers to decide the one that would better address it. The following decisions regard the number of users (that appears to be correlated to the kind of experience) and the level of immersion (that influences the choice of devices and depends on the previous elements). The final choice is one regarding the type of representation since this choice does not profoundly affect the previous ones. The framework is intended to be used after the designer has identified the behavioral aspects that need to be addressed depending on the target users (e.g., they need to increase emotional involvement or instead practical knowledge). Identifying the main behavioral sphere to address allows visualizing possible sets of features rapidly. However, there is no specific direction to follow: the same features can be used to achieve various objectives to different extents. Moreover, depending on the case study, designers will target one sphere more than the others: for instance, a robust emotional experience might not be the most suitable for practitioners, while it could be optimal for fundraising. Nevertheless, they should keep in mind that each dimension can support the others: stimulating affection for nature can strengthen professionals' motivation, and explaining facts and data will support the fundraisers' credibility. The framework also highlights possible gaps to be explored while making designers aware that the lack or scarcity of case studies presenting a particular feature in a specific sphere might be due to the presence of criticalities.

Not only designers will be empowered in the ideation and implementation of behavior change strategies through VR experiences, but they will also be enabled to expand these effects further, supporting other designers in product and service development processes. The diffusion of tools and methods will increase the knowledge, quality, and potential of VR. Moreover, the development of future frameworks and models will be affected by VR applications' evolution. With the increasing use of VR tools, required by—and enabling—remote communication and collaboration, new needs will arise. A possibility is that VR applications will progressively adapt to users, with the implementation of more dynamic and flexible virtual environments. This is likely to enhance VR potential significantly, as well as the complexity, making the necessity of design guidelines even more relevant.

Designers should consider several risks and limitations of using VR tools without carefully managing all the aspects and considering a possible negative impact on users [42], especially if intended as a mere replacement of real-life experiences [46]. However, as discussed in this work, VR can provide several experiences that are not available in reality or that might not be available in specific times and for part of the population (an example is the recent reduction of people's free circulation around the world). The overcoming of a global crisis and challenging events such as the current ones may be an opportunity to change people's habits and make wiser decisions, driving a transformation towards a more sustainable economy and society. VR can play a role in this scenario, shortening distances between people, events, and possible solutions.

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