A design methodology for affective Virtual Reality

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Highlights

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- We designed ten virtual environments able to elicit a specific emotional reaction.
- We describe the methodology we used to design the emotional virtual environments.
- The methodology is based on the use of semantic elements and valence, arousal and dominance.
- The results show that the designed virtual environments elicit the desired emotions and arousal-valence-dominance levels.

A design methodology for affective Virtual Reality

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Abstract

In the era of 'metaverse', virtual environments are gaining popularity among new multimedia contents and are also recognized as a valuable means to deliver emotional content. This is favoured by cost reduction, availability and acceptance by end-users of virtual reality technology. Creating effective virtual environments can be achieved by exploiting several opportunities: creating artificial worlds able to generate different stories, mixing sensory cues, and making the whole interactive. The design space for creating emotional virtual environments is ample, and no clear idea of how to integrate the various components exists. This paper discusses how to combine multiple design elements to elicit five distinct emotions. We developed and tested two scenarios per emotion. We present the methodology, the development of the case studies, and the results of the testing.

1. Introduction

The interest towards human emotions is constantly growing in numerous application fields: from pure entertainment [117] to marketing [6], but also in work-related issues [5, 74], as well as in human-computer interaction [27], and human-robot interaction [18]. There are numerous attempts to develop solutions able to understand human emotions starting from a series of data collected on the person. Knowing the emotional reaction of a consumer when interacting with a product might help a company to understand whether the product will be successful on the market [80, 30]. Detecting users' emotions, as part of user experience, while interacting with interfaces can help to increase the quality of the interface itself [40]. Examples of benefits of detecting emotions can be observed in facilitating car driving [77], or to improve human-robot interaction [79] to name a few.

At the same time, there is a tendency of generating human emotions through a series of multimedia contents. The applications are numerous, from pure entertainment to well-being reasons, up to medical and rehabilitation issues. Inducing specific emotions has also been proven to favour creative activities [52]. The multimedia sources that can be used to elicit human emotions are many, and they can vary from a static picture to a sound or a video sequence. A technology that certainly is considered interesting and promising in this sense is Virtual Reality (VR). Thanks to its complexity and flexibility, it offers numerous possibilities for eliciting human emotions. In principle, VR can be used to immerse the user in a completely simulated world where any detail can contribute to arousing a particular emotion. Those include visual, auditory, tactile and even olfactory aspects, combining the various media used up to now to elicit emotions. Moreover, differently from the other media, VR is interactive since the user is stimulated and reacts to what happens in the Virtual Environment (VE).

However, while various databases of images [17, 29], sounds [16], and videos [12] have been validated for their ability to raise specific emotions, there is no validated set of VEs that can be used for similar purposes, except for few emotions such as Awe [24].

What is more important is that there are currently no guidelines or methodologies for VR designers to create such environments. Developing a methodology is important when making a design activity that must be repeatable, transferable, and systematic. The risk of not creating a method is that of not having guidelines when tackling the problem again. This is not a trivial task due to the complexity of the emotions themselves and to the complexity of designing a VE.

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In fact, the design space available is large, with various parameters that can be adjusted and combined in several ways. For instance, the designer can create realistic environments, mimicking existing situations where the emotional reaction is known, as well as completely unrealistic worlds, where anything can happen. Moreover, the experience delivered to users can be unisensory or multisensory: this requires managing and integrating visual and auditory stimuli, but also tactile and olfactory ones. The user can freely explore the environment, or the designer can decide to constrain the movements to follow a specific path, or rather adopt an approach in between the former two, providing hints and suggestions. However, there is always a degree of freedom: as a consequence, stories experienced by different users might be similar or might differ, making VR different from traditional media. Which are the hints for a VR designer to understand how to deliver a specific emotion through an interaction? VR users can interact with scene objects to different extents and in different modalities, in terms of input (users' gestures and movements) and output (feedback from the VE). Objects in the virtual world can be static or dynamic, drive users' attention to be simply observed, or rather represent obstacles, suggest or require users to take a specific action. Hence, they can express a variable impact or control on users' decisions and experiences. Objects can also have a specific meaning, depending on the story the user is experiencing in the VE.

In the paper, we describe the methodology used to design ten affective VEs whose aim was to elicit different emotional states. We operated an initial general categorization of our scenarios according to five emotional entities (i.e. happiness, sadness, anger, fear, and disgust), and we proceeded with the identification of the various design elements considering their assessment on the three emotional dimensions of valence, arousal, and dominance.

2. Related Works

In this section, we explore the most common theories and models on human emotions and the potential of VR to elicit emotions.

2.1. Emotions theories and models

Finding an effective method for understanding and describing emotions has been a topic of scientific discussion for more than a century. Even today, it is not yet possible to find a total agreement on which theory or model is the most valid. Darwin [31] provided the initial basis for the development of the basic emotions approach, taken up in recent times by Ekman and Friesen [37]. Wundt [127] work is instead considered as the first step towards the development of dimensional models, further developed in the last century with a constant: the identification of three principal dimensions able to explain through different combinations most of the different emotional states that can be experienced. These three dimensions have been consistently reported over the years with different names. Wundt [127] labelled them as pleasure, tension and inhibition; Osgood et al. [84, 85, 86] defined them as evaluation, activity and potency; Schlosberg [108] listed them as pleasantness-unpleasantness dimension, attention-rejection dimension and the level of activation; while Russell and Mehrabian [69, 70, 102, 103], identified them as pleasure, arousal and dominance.

In a subsequent step in the comprehension of emotions, Russell [99] re-elaborated Wundt and Osgood's model by graphically displaying the distribution of different emotions in terms of pleasure and arousal. The model, called the Circumplex Model of Affect, is constituted by a circular structure in which four quadrants can be identified by the two bipolar axes denoting the pleasant/unpleasant continuum (horizontal axis) and the unaroused-aroused continuum (vertical axis). The intersection of the two axes corresponds to the mid-point of both continua, indicating a level of neutrality.

Moreover, in order to directly assess the emotional response to an object or event and to overcome the use of verbal ratings, a graphic tool was introduced with the Self-Assessment Manikin (SAM) [15, 49, 61], a solution that maps the three dimensions of pleasure (also defined as valence), arousal and dominance into three non-verbal pictorial scales.

Nevertheless, despite the unequivocal utility of emotional dimensions, it is undoubted that humans are able to recognize and also categorize emotions. For some people, this categorization is simply based on the dimensions described above (i.e. valence and arousal); for others, it is more detailed, allowing a more differentiated emotions recognition [11]. Despite the possible issues and differences linked to language and emotions, Ekman and Friesen [37] delineated a group of facial expressions of emotions considered to be shared universally: anger, fear, disgust, sadness, happiness, and surprise. Ekman's theory and assumptions on the existence of "basic" emotions have been criticized during the years (e.g. [100]), but the progress of the research in the field seems to have reached an agreement about the need for models based on dimensions that help to explain and measure emotions, and also the existence of a "basic" categorization constituted by at least five emotions (i.e. anger, fear, disgust, sadness, and happiness), while less consensus is visible on the inclusion of surprise, shame, and embarrassment [36]. Other theories developed in emotion research [106] argue that emotions are the result of both physiological and cognitive processes challenging the existence of basic emotions, inspiring contemporary models of core affect, although with some differences. The major current proponents are Russell [101] and Barrett [10] with their revolutionary research in psychology and neuroscience [26, 63, 64]. It is indeed well known that basic emotions are not the only emotions a human being can experience. In this activity, the aim was to propose a design methodology for VEs capable of eliciting easily distinguishable and recognizable emotional responses. For this reason, we decided to focus on a limited number of discrete emotions, while knowing that future development will need to include most diverse variations typical of human emotional experience.

2.2. Virtual Environments to elicit emotions

VR potential to raise a variety of emotions has been acknowledged for different purposes and in several contexts. In fact, it has often been defined as the ultimate empathy machine [9, 48]. VR is an effective means for therapeutic uses, for instance, to induce relaxation and feelings of emotional well-being [20, 81]. Another example is the use of VR exposure therapy to treat phobias and post-traumatic stress, involving and modulating fear responses [67]. VR can stimulate changes in mood both in positive and negative ways, eliciting happiness and relaxation, but also anxiety and sadness [8].

A possible way to raise a specific emotion through VR is by selecting and presenting tailored contents. For instance, Banos et al. [8] induce positive and negative emotions by integrating into the VE Velten statements [121] and validated media, including music, IAPS images, and movies. Sad emotional reactions can also be elicited through the combination of Velten sentences and IAPS images [7].

Felnhofer et al. [39] instead control parameters in the virtual environment (lighting, weather, and time of the day) to stimulate joy, sadness, boredom, anger and anxiety. Naz et al. [78] define design principles to obtain affective responses using colors and brightness in VEs. Another possibility is replicating real environments related to certain emotions; like in the real world, presenting VR natural environments, compared to urban scenes, can support relaxation [47]. Specific elements can induce certain emotions; Chirico et al. [24] used a waterfall, mountains and space view to create awe. Hence, when considering the contents, both sensory aspects (e.g., colors, lighting) and semantic aspects (e.g., the representation of specific objects or places) can be relevant when designing the VR experience. However, other aspects that are proper and unique to VR itself, like exploration and interaction with the environment, can play a fundamental role. As an example, Barbot and Kaufman [9] investigate the mechanisms behind empathy change in VR, finding that user experience factors, especially agency and embodiment, can be more determinant than the contents themselves. An important aspect when eliciting a particular emotion through multimedia content is to provide the user with an illusion of being part of the experience. In the VR field, this is known as the sense of Presence, which is generally defined as the "sense of being there" [51, 109, 111, 126]. Using Virtual Reality instead of traditional movie clips can help in terms of creating a first-person experience. Interactions between the level of presence and the emotional experience have been consistently reported in the literature [34, 96], and despite there is not total agreement on the nature of this interaction, there seems to be a link between the level of immersion experienced in the VE and the emotional response, especially in terms of activation (i.e. arousal) [34]. In this regard, the level of immersion in VR can be defined in different ways. One describes how users feel perceptually and psychologically enveloped and interacting with the VE [110]. Another is related to the kind of technology used (i.e., immersive Head-Mounted Displays (HMD), non-immersive PC screens) as an objective feature of the system [112], that can also be multisensory and include auditory, haptic, and olfactory devices. The former appears to be related to the interaction aspects, including the actions the user can accomplish and the feedback provided by the environment. In particular, ease of interaction, meaning a fluid, transparent, natural interaction perceived as simple and intuitive, is associated with positive emotions [87] and negatively associated with distress, worry and frustration [57]. Conversely, frustration arises when the progress users are making towards achieving a goal is impeded [43]. This feeling can also be obtained when people feel unable to use technology as a consequence of difficult interactions [104].

Another factor that can be manipulated to affect emotions is agency, meaning the feeling to control the virtual character and its actions in the VE have an impact on perceived dominance [124]. Higher levels of dominance are correlated to positive interactions and dialogues in VR, while lower levels are present in negative conditions generating anxiety [46].

However, it is possible to conclude that, to maximize the effectiveness of VEs to raise emotions, both aspects related to the specific contents and the overall user experience should be considered and integrated.

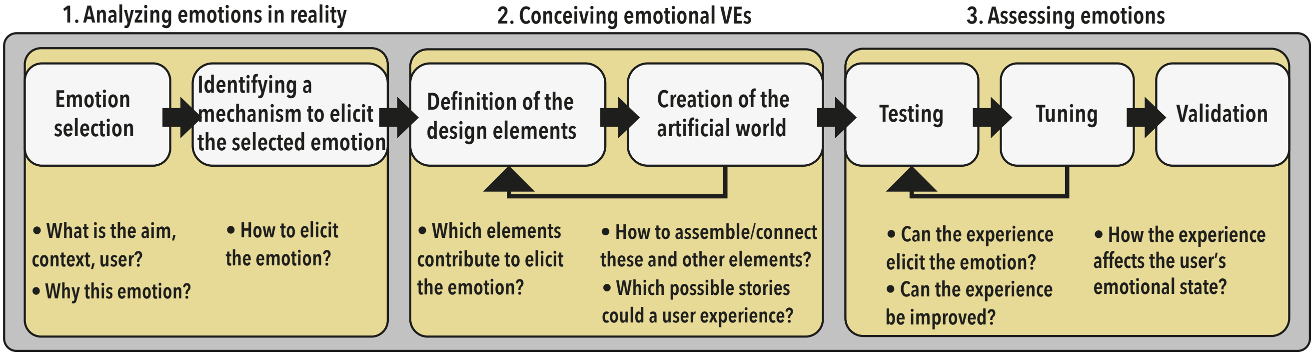

Figure 1: The methodology adopted to design VEs able to elicit emotions

Through this work, we aim to define an initial guideline for the identification of design elements and their use for the creation of affective VEs. Furthermore, we will show the results obtained after an initial validation of the design elements identified with our methodology on the dimensions of valence, arousal, and dominance.

3. Designing Virtual Environments able to elicit an emotional reaction: methodology

VR is a technology that combines multisensory stimuli to generate the feeling of being "present" within computer-generated environments. It gives users the possibility to interact with 3D contents, resembling real-life interactions. From a methodological perspective, designing a VE is not that different from designing a complex and multisensory interactive real experience. In developing this design methodology, we took inspiration from the traditional design practice in the context of engineering and design, extensively described in the work of Ulrich and Eppinger [119], and from the best practices of User-Centered Design.

The design of VEs aimed at raising emotions requires to manage, combine and integrate different aspects which are usually considered and handled individually in other media channels, especially in terms of deployed sensory channel, content and user experience. VR has been used to elicit emotions in different contexts, such as psychotherapy [95], exposure therapy [41, 88] or training purposes [65]. However, the emotional responses considered are often limited and the methodology guidelines used to induce them are rarely the main object of the study.

In the current work, we present a methodology in which the overall experience will be based on several design elements (e.g., concrete and abstract objects displaying multisensory qualities, dynamism and interaction features) assembled in a way to create a new artificial "world" for the user. In this world, multisensory attributes like shapes and colors, sounds, but potentially, even tactile and olfactory components (that can be also evoked or enhanced by the other senses) are affected by the user's actions. Hereafter, we illustrate the methodology shown in Figure 1 and explained in Section 3.1. It consists of three phases that are composed of seven steps:

1. Analyzing emotions in reality
   (i) emotion selection
   (ii) identifying a mechanism to elicit the selected emotion
2. Conceiving emotional VEs
   (i) definition of the design elements
   (ii) creation of the artificial world
3. Assessing emotions
   (i) testing
   (ii) tuning
   (iii) validation.

3.1. Overall methodology

The first phase of the emotional VR design is to set the objective of the design methodology, meaning to define which emotions to be elicited and understand their underlying mechanisms.

The choice of the final emotions to be aroused depends on the future objective of the study within which the VE is involved. In our case study, five distinct emotions (i.e. happiness, anger, fear, disgust, sadness) have been considered.

When desired emotions are selected, the subsequent step is to identify an underlying mechanism that can be deployed to elicit the desired emotion. From a design perspective, it becomes core to understand when it is possible to rely upon only the three dimensions of valence, arousal, and dominance and when it is instead required to introduce a further level of categorization based on more specific emotions. If the aim is inducing a generally positive experience, the adoption of criteria based on the single pleasure dimension (positive valence) could be sufficient. The same criteria could be adopted even if the goal is to evoke a specific positive emotion such as happiness; though, the embedding of semantic elements related to pleasure, spare time, lightheartedness would plead the cause and make the emotional response more specific. Instead, the entanglement of opposite semantic elements (sense of loneliness, neglect, pollution) within a negative valence-based scenario could be used to elicit sadness. If the aim is to arouse fear in the user, general unpleasant elements (negative valence) could not be enough, requiring the further involvement of elements referring specifically to the horror/thriller semantical context. Fear can be generated by a perceived threat, and it is strictly linked to the startle element, which can be defined as the physiological response to a sudden and unexpected intense stimulation [97]. Similarly, surprise is the result of an unexpected event that results from a mismatch between one's mental expectations and the environment, but the startle component is usually diminished in pleasant emotional contexts [60]. One of the most effective mechanisms to arouse anger is based on frustration, which consists of the perception of obstacles that limits the achievement of a goal. Disgust is characterized by a feeling of aversion, but, even though it is generally linked to sensory perceptions related to insidious animals [83] and offensive substances such as feces and vomit, i.e. the so called "core disgust" [82], it may also include social dimensions, such as "interpersonal disgust" (e.g., not wanting to wear clean used clothes [50]) or "moral disgust" [82], related to immoral behaviour [98].

Once the emotions are chosen and outlined, the environments can be conceived through a twofold process. The adoption of specific design elements (first step) will be deepened in Section 3.2 and should be complementary to the creation of a new artificial world (second step).

The world is the scenario the user interacts with, in which emotional elements can be added or excluded also according to their coherence with a narrative (e.g., a shark could be a fear element, but it would not make sense in dark wood). Creating an interactive world makes this methodology specific for VR, as interaction is VR's primary constituent element. This step refers indeed to the possibility of letting the user make their choices, so that they feel to own the narrative. Also, the mutual influence between the user and the environment enhances the effects of agency and presence, enriching the emotional response and contributing to achieve the desired emotional state.

Content-wise, the information can belong to reality, can be digital, or a combination of them (mixed). The way to experience these contents can be completely passive or interactive. If the content is digital, interactive, and the interaction is natural, we typically define it as VR. Recently, some practitioners have even considered VR situations where real environments are acquired through 360 cameras and experienced through interactive technologies typical of VR (e.g., HMDs). Though, in digital or mixed content, like ours, the number of degrees of freedom offered in creating a story is much greater than using 360 videos. Indeed, in the type of VEs conceived in this study, environments can mimic reality or be completely fantastic. Therefore, during the development of our case studies, we have tried to take into account different degrees of freedom that can influence users' emotions and that could not be considered using other media, characterized by constraints such as an immutable environment, an absent interaction, or a reduced multisensory component.

Designers might know that single elements work relying on previous literature and case studies, but they cannot completely or precisely predict their synergic effect. When creating the artificial world, the designer can imagine an ideal story, or more specifically, a subset of possible stories happening into the world, depending on the user's choices and exploration mode. However, when testing the VR experience, more possible stories will probably emerge. The process, therefore, is not linear, and the final outcome will determine how elements are presented to the user, how the user will interact with them, how the user tours the fictitious world. For instance, slight variations on the arousal dimension may correspond to small changes in the intensity of a general positive affective state, while introducing design elements typically associated with specific emotions may induce a whole different change in the overall experience.

When a VE is designed, the desired emotional outcome is questioned to assess its effectiveness. The first step from a User-Centered Design viewpoint is to create a VR prototype to be primarily tested on a limited number of participants, that are asked to navigate the environment. We refer to this as 'pilot test', or testing. The purpose of this preliminary test is to understand possible behaviors in the scene, e.g., reactions to cues, and to uncover bugs/issues and unwished contingencies of both system and user. If such happenings occur, an adjustment to the environment (or to the questionnaire administration) is required. The adoption of questionnaires supports the design methodology in the assessment of the desired emotional outcomes. This process belongs to the tuning step and may concern several iterations, depending on the outcome of the pilot test(s). The testing and refinement process is similar to other product development processes lent from the industrial design field [119]. Moreover, similar models are used in the practices of User-Centered Design, for instance, for software development [123] or application design [68].

When all the material has been refined, the final validation can be performed with the involvement of a larger and more diverse group of participants. Emotional validation could be carried out with the aid of self-evaluation approaches, like questionnaires, and/or technologies for emotional assessment, such as facial expression recognition techniques, thanks to the adoption of a camera to acquire the face [120], or physiological data, e.g., heart rate, skin conductance, electroencephalography (EEG) [58].

3.2. Design elements

When the elicitation of specific emotions is desired, the process of identification, selection and merging of the design elements should be careful and tailored. In particular, it is possible to distinguish four aspects and elements that impact emotions:

- semantic elements;
- sensory elements;
- dynamism;
- interaction.

As shown in Figure 2, semantic elements are the starting point; they are converted into sensory stimuli through abstract and concrete elements. Concrete elements clearly represent real world recognizable objects and living beings (e.g., a flower, a dog, a building), while abstract ones cannot be identified with specific entities (e.g., a round shape, a bright color, a melody). Chirico et al. in [24] use concrete elements to induce awe, while Pinilla et al. in [90] describe abstract elements to raise different emotions. Dynamism, meaning the movement of both the virtual objects and the user, is also conveyed through senses (e.g., seeing the virtual characters changing position in the space, hearing their own steps into the environment). Similar elements are also used in [90] in the design of VEs visually representing emotions. This is true also for interaction elements: users see cues (e.g., signs indicating where to go) and perceive obstacle (e.g., objects preventing them to move further or reach a specific point in the virtual environment). Sensory elements impact the emotion considering valence, arousal, and dominance. Not only they affect all the three dimensions: they also have a synergistic effect. However, dynamism has an additional significant effect on arousal, immediately conveying the amount and type of events happening in the scene (e.g., amount of characters performing actions, active or passive behaviors, predictable or unexpected moves). Objects' movements can affect valence and arousal, providing a calming or stressing experience [90]. Interaction has a greater impact on dominance, suggesting and preventing users to accomplish actions or move in a direction (e.g., guidance signs, constraints, barriers), or rather living them completely free to choose. For instance, preventing users' to reach their goals can cause frustration [43], as well as the lack of interaction with the environment [113]. As discussed in Section 2.2, many VR properties can like presence, immersion, and agency, can enhance affective responses [23] and affect arousal [34], valence [54], and dominance [124] in different ways. However, this work is not focused on the manipulation of these properties (every scenario is tested using the same devices, users have no body avatar, and they are allowed to perform the same movements). For this reason, these features are not considered in the model.

3.2.1. Semantic elements

Semantic elements are signifiers conveyed by the VE. They are the starting point when designing the VE because their choice answers the question: what should the environment communicate to users so that they feel a specific emotion?

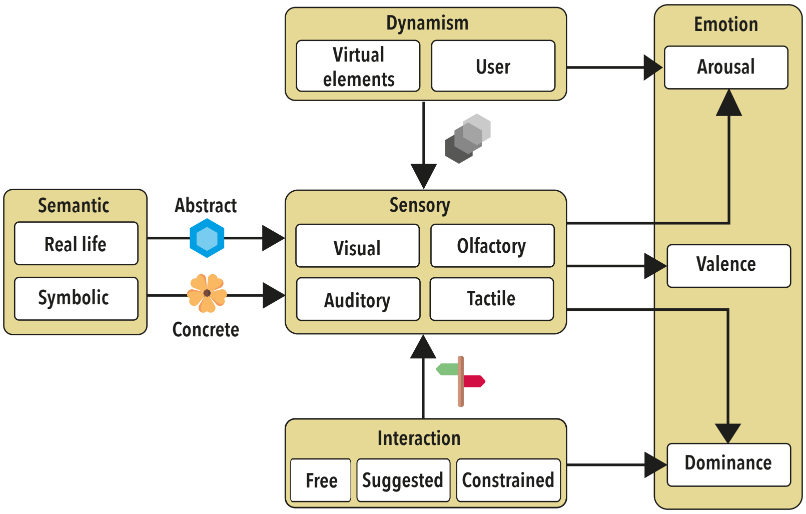

Figure 2: The design elements and their effect on emotional dimensions.

Real life experiences Elements based on real-life experiences recall places or situations associated with certain emotional states (e.g., the meaning of vacation can be conveyed by a beach, recalling memories of vacations and feelings of freedom and relaxation, the concept of suffering and loss can be conveyed by a hospital, reminding people about past tragic events or periods).

Symbolic meaning Elements based on symbolic meaning derives from our culture or literature and movies. The ideas of darkness and the unknown conveyed through environmental lighting conditions and supernatural creatures (e.g., monsters, zombies) are among the main elements creating fear in VR games [62]. The concepts of childhood and friendliness are found in animation movies characters (e.g., colorful, fantastic animals or vegetation). In fact, characters with baby-face (round features and big eyes), bright colors and happy facial expressions facilitate positive emotions [91].

3.2.2. Sensory elements

Semantic elements are delivered through sensory elements that include visual, auditory, tactile and olfactory cues. Moreover, they include crossmodal representation [114], as stimuli in a modality can recall mental imagery of other modalities.

Vision Visual elements include the use of abstract elements (colors, lighting, textures, and forms) and concrete objects (e.g., characters and vegetation). They express the time of the day (e.g., dark or bright environment) and can enable or prevent users' visual perception. Both concrete and abstract elements can elicit semantic meanings. For instance, concrete, natural elements like mountains, forests, or oceans, can represent the idea of nature as positive, healthy, recreational, recalling freedom and well-being, as done in much commercial advertising [44]. Abstract elements like colors also have specific semantic meaning in different cultures. For instance, green and pink have a positive valence [42, 93]: green represents safety, health, calmness, nature; pink recalls femininity, optimism, and desire. A color can have more than one meaning association: for instance, red can represent danger or love, depending on the context [66, 93]. For this reason, it is important to contextualize colors in the Virtual Environment. Grey and black can be associated with exclusivity, luxury, and power [66]. However, in a VE, a dark sky is linked to negative valence [90]. Considering arousal, red and grey can be respectively considered as active and passive color [66]. In VR, bright saturated colors are associated with high valence and arousal, while less saturated colors can be perceived as more calming [90].

Sound This category includes the presence of natural sounds and noise produced by specific elements in the scene, as well as music. They can be directional or not. Like visual elements, sounds can be concrete or abstract. Concrete sounds can be associated with specific real objects, living beings or environment: for instance, sounds of twittering birds, associated with nature, can have a relaxing effect [3]. Abstract sounds can include a melody or music. Music is evaluated as more arousing when its rhythm is faster, while valence is given by atonal (negative) or tonal (positive) [35] components. Effects of human non-verbal sounds, in particular considering negative emotions (e.g., screams, crying), are shared across different cultures [105]. Moreover, harsh, unpredictable sounds are usually produced by mammals in stressful, alarming and dangerous situations. For this reason, non-linear sounds, or music including noise or abrupt frequency or downshifts, have a negative valence and high arousal [14]. In fact, sudden, unexpected sounds can cause fear or surprise, as observable from their use in comic and horror movies. Instead, constant noise is more easily associated with frustration and anger [39].

Touch Elements resulting from the tactile exploration of the scene and interaction of different textures, shapes, and materials. They can also be expressed through sounds (e.g., users hearing themselves stepping on a surface). The sense of touch can play an important role, especially for certain emotions, like disgust and fear [1, 22], where particular textures can evoke specific objects and their correspondent meaning (e.g., squashy material can be identified as mud and be associated with dirtiness). Touch elements can also be concrete or abstract: the former is associated with a specific object, situation, or material, while the latter can only be described through the kind of sensation elicited. Considering a concrete dimension, touch is fundamental in social and interpersonal contexts, and it has gained interest to enhance remote communication. For instance, squeezing is related to high arousal and negative valence, while finger touch is relaxing and pleasant [94]. Regarding abstract tactile stimuli, their amplitude, frequency, duration, and envelope can affect valence and arousal dimensions [128].

Smell Olfactory elements are related to the presence of objects having specific scents in the scene. For instance, flower scents in VR can play a role in promoting relaxation [2]. Scents consistent with the VR experiences can enhance the sense of presence and have a high emotional impact [76, 122]. Several crossmodal correspondences have been found between olfaction and other sensory modalities, such as vision (e.g. odors and colors [32], odors and shapes [45]), or audition [13, 28]. These correspondences have been proved to affect also emotional responses [114, 72] and studies on the affective feelings induced by odors are available [25, 92].

3.2.3. Dynamics

Dynamism in VR includes dynamics associated with both the user and the scene. Dynamics is fundamental to convey what is going on in the virtual environments, delivering an experience that is full of events or rather void, with a varying evolution and predictability. For this reason, they are specifically related to arousal. However, the user's types of allowed movements and velocity are also strongly linked to the "feeling in control" or, oppositely, the "feeling under control" sensations; thus, dynamic choices in the virtual environment may contribute to affect the dominance level. In fact, user's dynamism is related to the perception of obstacles and constraints, or rather freedom.

Objects and environment movements The virtual environment can vary depending on the number of objects moving, on the type of movement (e.g., velocity, direction), and on the variation of movement (e.g., sudden vs constant). Dynamism can impact significantly on emotions, especially on arousal. For instance, slow objects moving up have a calming effect, while fast, repetitive movements can raise stress [90].

User movements The user is an active and moving element into the environment. Movements can be constant or variable, fast or slow. VEs can affect arousal and, as a consequence, movement behavior in different ways [75]. However, the designer can set one or more speeds for the virtual avatar of the participant (e.g., walking, running) and the possibility to perform certain movements (e.g., jumping). This can impact emotions: for instance, the feeling of speed in video games can be a source of thrill [55].

3.2.4. Interactive elements

Interactive elements can be divided into two categories. Guidance elements and exploration cues provide users with indications or suggestions on how to move in the environment. Obstacle and surprise elements provide feedback to users actions, affecting their behavior in the environment (e.g., preventing users from continuing on their way or scaring them, making them change direction). For this reason, they involve dominance, which is related to how users feel in control or instead dominated by the environment.

Table 1
List of the main design elements used for our ten affective VEs.

	Sensory elements (visual, auditory, tactile, and olfactory)	Semantic elements (real life experiences and symbolic meaning)	Dynamism elements	Interaction elements (guidance/exploration cues and surprise/obstacle)
Happiness	1: bright, unsaturated colors, wind/ocean sound, birds chipping, sunset light, beach, vegetation, air balloon. 2: bright saturated colors, loud music, many colored light source, funny characters, fairy houses, sweets.	1: vacation, nature, free time. 2: party, fantasy, friendliness, childhood.	1: a light wind moves sea and vegetation, air balloon fluctuates. 2: quick, dancing movements of characters.	1: path to follow, growing ocean sound 2: surprise funny sounds when close to characters.
Sadness	1: unsaturated colors, hospital, crying people 2: greyscale colors and sky, sad music, dead animals/vegetation, factories, nuclear symbols.	1: suffering, illness, loss 2: industrial, apocalypse, toxic, hopeless.	1: static environment, except people shaking and crying. 2: static environment.	1: sounds of people suffering from the bedroom 2: indication (arrow on the ground).
Anger	1-2: unsaturated colors, red light, repetitive alarm sound, countdowns, smoke, labyrinth environments.	1: emergency, pressure, failure. 2: no escape, pressure, failure.	1: quick change of view. 2: quick and repetitive falls.	1-2: invisible obstacles, failure sounds and constant restarting process.
Fear	1-2: dark unsaturated colors, low light and visibility. A mix of classic horror elements (zombies, monsters, howling wolves, crows) and elements deliberately opposed to the environment (distorted children's laughter, clowns).	1-2: darkness, unknown, death, supernatural, mystery.	1-2: static environments, fast movements or the sudden appearance of surprise elements.	1: monster appearing, tv turning on, doors shutting or opening. 2: zombie appearing, light turning off, crows flying close to the user.
Disgust	1: vision/sounds of animals associated with dirt (beetles, rats), excrement, green gases representing bad scents 2: vision/sound of insects and sickness, audio feedbacks of walking on a mushy material, chemical toilet, excrement, rotten food.	1-2: carelessness, dirt, sickness, diseases.	1-2: quick animals movements.	1-2: interactive sounds of people feeling sick and movements of animals depending on user location.

Cues: guidance and exploration Guidance and exploration cues are placed in the scene, inviting users to perform (or avoid) actions and movements (e.g., an open door, a pathway). These elements provide guidance but could also attract and entertain users. Cues can be designed to raise attention and stimulate exploration (e.g., a curious sound or object) or make users change direction (e.g., a barrier, an unpleasant object). Balancing these elements allows maintaining certain properties in the experience for every user without limiting their sense of agency and freedom of exploration [125].

Obstacles and surprise elements The response obtained when trying to accomplish the action or movement. The user may be able to proceed as expected or encounter obstacles. Moreover, surprise elements may appear in the process. For instance, they can be used to create fear [62]. Obstacles, challenges and failure can be used to raise frustration and engagement [73]. In VR, obstacles and surprise elements can be considered as feedback because they are activated on specific occasions, for instance, when users reach a certain point in the virtual space.

4. Case studies

We developed ten scenarios, two for each of the five distinct emotional entities exposed in section 2.1, (i.e. anger, fear, disgust, sadness, happiness) containing design elements mapped on the valence and arousal dimensions. Table 1 lists the design elements we included in each scenario. The following subsections expose in details how environments were created using the described elements. Figures 3 and 4 illustrate how the methodology was used to design the environments eliciting fear and happiness, respectively. Moreover, they show how the environment's design elements listed in Table 2 impact arousal, valence and dominance.

4.1. Happiness

Scenario 1 Users find themselves on a pathway in the middle of a tropical beach with tall palm trees at sunset time. They are attracted by the sound of waves and can walk towards and into the sea, where they see seashells and fishes, while in the sky, there are air balloons and birds (Figure 5a).

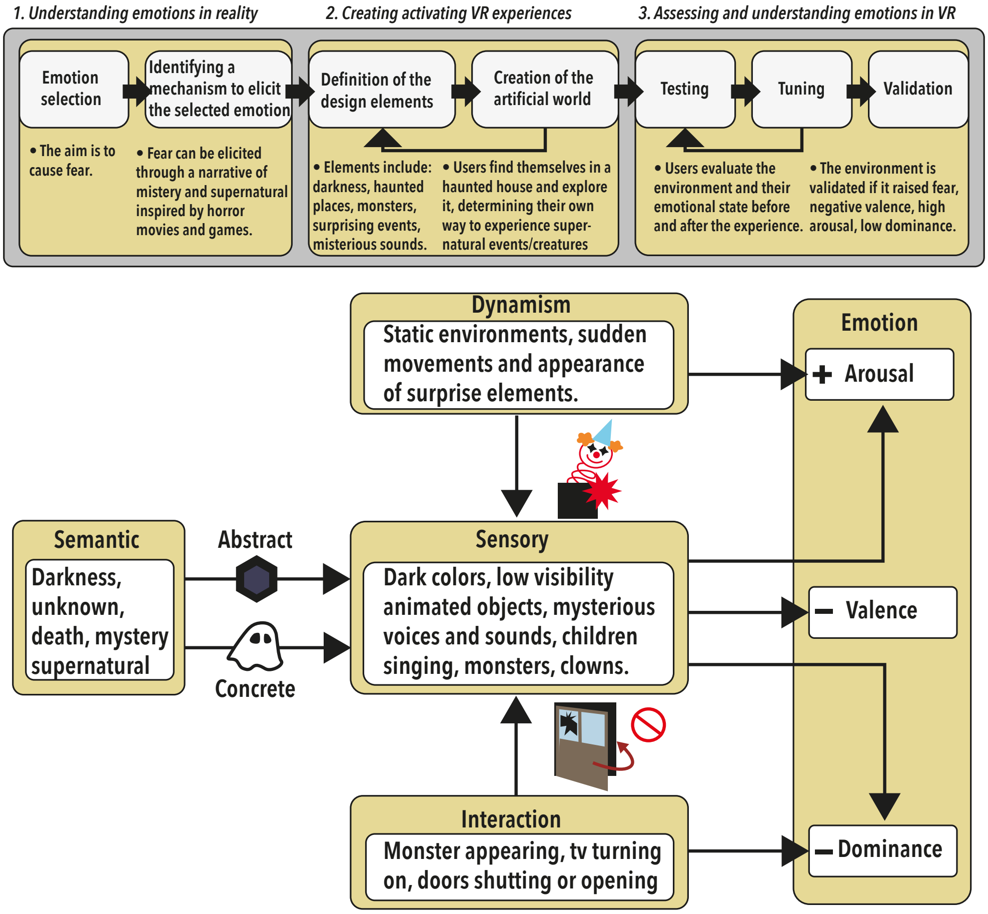

Figure 3: Example of application of the methodology to create an environment eliciting fear and representation of how elements affect arousal, valence, and dominance.

Scenario 2 Users find themselves in a fantastic rainbow world with fairy houses, colored light bubbles, and huge sweets and lollipops. They are attracted by fantastic characters that emit funny sounds when they walk closer (Figure 5b). Loud music is playing, and characters move like dancing.

4.2. Sadness

Scenario 1 Users are in the waiting room of a hospital, hearing the sound of a clock and people crying. They can walk into another waiting room, where they see medical equipment and a girl crying on a chair. Then they can walk into a room with suffering patients complaining and shaking (Figure 5c).

Scenario 2 Users are in a post-apocalyptic scenario, at a crossroad, where they see an arrow on the ground indicating to proceed along a wide street. There are dead animals on the ground, litters, and dead vegetation on the sides. The surrounding is grey and industrial, and there are signs of radioactivity (Figure 5d). A piece of sad music plays while they walk.

4.3. Anger

Scenario 1 Users are in school; they see smoke and hear a fire alarm (Figure 5e). There is a countdown pressuring them to escape, but when they walk into the classroom, they continuously find invisible obstacles on the way, followed by a fail sound and a red flash. Then, they restart from the initial position.

Scenario 2 Users are shown a ranking of false excellent scores obtained by other users. Then they are immersed in a hedges labyrinth, from which they have to get out. The labyrinth is filled with invisible obstacles and traps, which

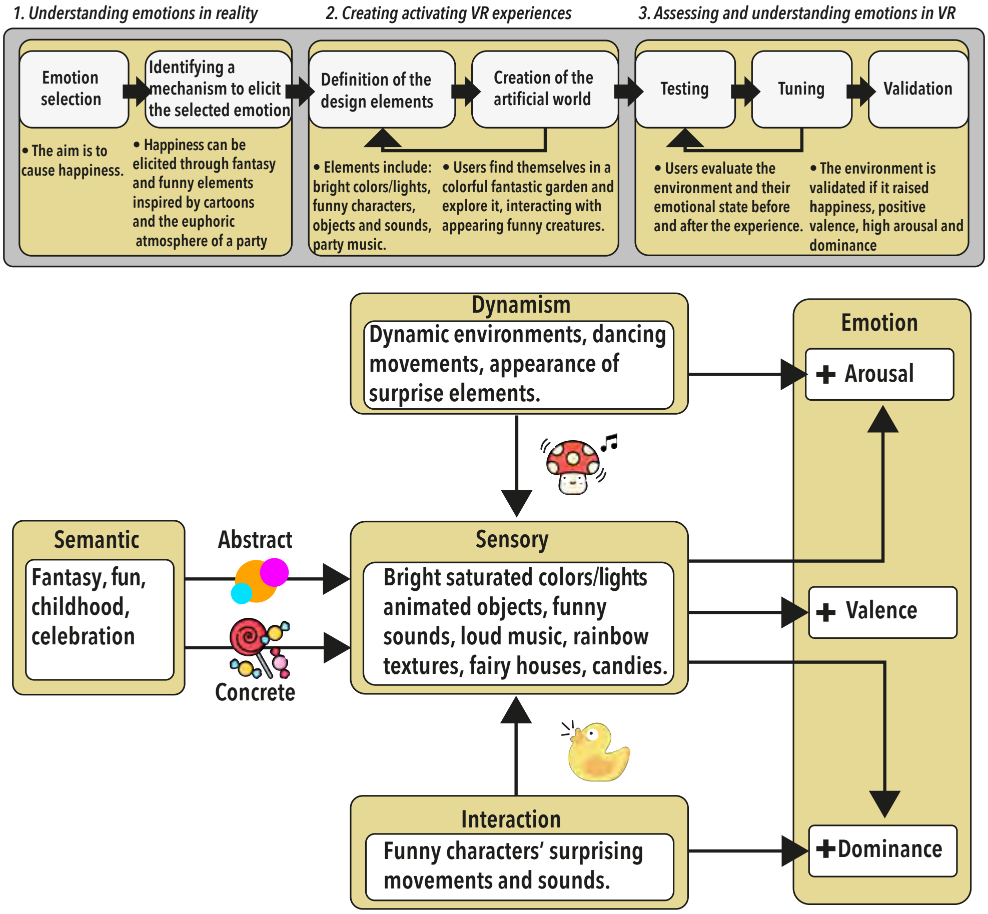

Figure 4: Example of application of the methodology to create an environment eliciting happiness and representation of how elements affect arousal, valence, and dominance.

cause the users to restart from the initial position after hearing a fail sound, seeing a red flash and falling into a void (Figure 5f).

4.4. Fear

Scenario 1 Users are into a dark house and can walk along a corridor, hearing voices and seeing disturbing pictures on the wall. They can enter different rooms, and triggers are activated when they walk by (e.g., clown suddenly appearing in Figure 5g). Finally, they can hear a noise and find a monster right behind them.

Scenario 2 Users are in a dark wood on a dimly lighted pathway. They walk forwards while visual and auditory triggers are activated by their movements (e.g., a woman screaming, craws flying nearby, red eyes observing them among the side trees). Then they got into a small wooden house, where they see a corpse. If they get out, they see a zombie walking towards them (Figure 5h); while back into the house, the corpse disappeared, leaving a blood puddle on the ground.

4.5. Disgust

Scenario 1 Users are in an abandoned basement, with dirty WCs, excrement stains around, flies and roaches on the ground, squeaking rats, and green gases (Figure 5i). They can walk around the small basement that also has a low ceiling, making the elements look close to users.

(a) First happy scenario. (b) Second happy scenario. (c) First sad scenario. (d) Second sad scenario.

(e) First angry scenario. (f) Second angry scenario. (g) First scary scenario. (h) Second scary scenario.

(i) First disgusting scenario. (j) Second disgusting scenario.

Figure 5: Details of the affective VEs used to elicit Happiness, Sadness, Anger, Fear, and Disgust.

Scenario 2 Users find themselves in a picnic area in a wood, walking along a pathway with picnic tables with rotten food and dirty dishes (Figure 5j). When they walk by, they see roaches running away. Then they can get close to chemical toilets, hearing people feel sick.

4.6. Mapping design elements to emotions

As explained in Section 2.1, several studies provided correspondence between specific values of valence and arousal, and emotions. This correspondence has also been graphically represented on the Cartesian plane, with the valence on the horizontal axis and the arousal on the vertical axis, with the aim of locating emotions on this plane and defining a relationship between them [99]. We could do the same thanks to the contribution of "affective databases" (i.e., databases of content aimed at eliciting emotions in the user). The IAPS and IADS are two affective databases that provide, respectively, a set of images and sounds and specific values of arousal and valence for each of them [16, 17].

Thus, we could refer to IAPS (see Figure 6) and IADS (see Figure 7) databases [16, 17] to locate visual and auditory elements in the valence-arousal model and to create a list of elements of our VEs in relation to these values (see Table 2). In Figure 8 colors are mapped to valence and arousal according to [116].

5. Testing

In this Section, we present the testing phase of the VEs developed using our design methodology. During the testing phase, participants were asked to navigate through our scenarios in a semi-immersive set-up and to assess their emotional experience in terms of valence, arousal, and dominance.

The experiment followed a within-subjects design where the five emotional entities used to categorise our VEs, plus the baseline, constituted our experimental conditions. To facilitate the generalization of the results, each condition was constituted of two scenarios to generate slightly different experiences always linked to the same emotion. Standardized scenario selection and presentation order were counterbalanced between participants using a Latin Square design so that all scenarios were uniformly tested.

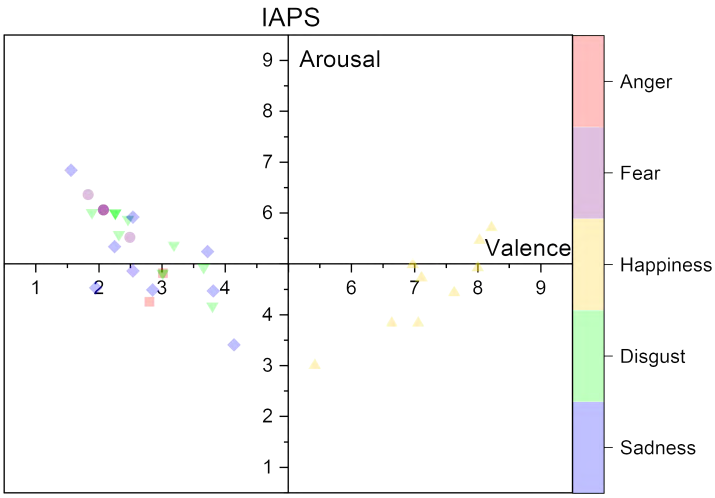

Figure 6: Distribution of the main IAPS design elements selected for our scenarios, based on valence-arousal rates.

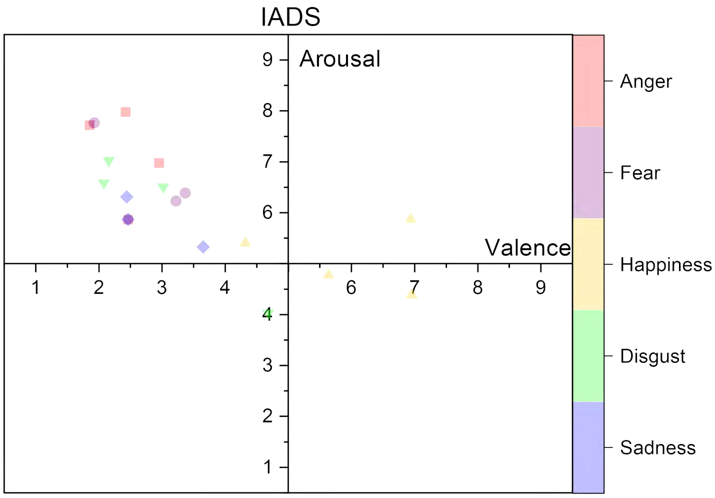

Figure 7: Distribution of the main IADS design elements selected for our scenarios, based on valence-arousal rates.

5.1. Participants

Forty eight participants (17 female), aged between 19 and 40 years ($M = 26{,}27$; $SD = 4{,}336$) voluntarily took part in the study.

5.2. Measures

In the following Section, we present the measures used to assess the empathy and alexithymia scores of our participants and to evaluate their emotional responses to our scenarios. On this point, several methods are available to measure emotional feedback. Together with self-assessment questionnaires, many physiologic measures have been explored in the study of emotions. Since physiologic activations are mainly involuntary, they may be considered as a more efficient way to collect emotions related data. Nevertheless, it is still difficult to map an unequivocal physiological pattern onto specific emotional states, as emotion perception is susceptible to variations from user to user, but also to other factors such as contexts [107, 115]. Moreover, common measures such as heart rate variability (HRV), electrodermal activity (EDA), electroencephalogram (EEG) require users to be connected with several sensors, and are strongy susceptible to motion artifacts [53]. Among the available methods, those who were best suited to providing basic emotions as an output, taken as theoretical reference, are self-reports and the analysis of facial expressions (FEA)

Table 2
List of IAPS and IADS elements with valence and arousal values

	IAPS			IADS		
	Element	*Valence*	*Arousal*	*Element*	*Valence*	*Arousal*
Happiness	Sea	8.03	5.46	Seagull	6.95	4.38
	Sunset	8	4.92	Wind	4.32	5.4
	Seagulls	7.63	4.43	Funk music	6.94	5.87
	Beach	8.22	5.71	Chickens	5.64	4.77
	Nature	7.06	3.83			
	Hot-air baloon	6.97	4.98			
	Candy	7.11	4.72			
	Mushroom	5.42	3			
	Balloons	6.64	3.83			
Sadness	Pollution	2.85	4.49	Man cough	2.46	5.87
	Cigarettes	2.54	4.86	Man wheeze	2.44	6.31
	Dead body	1.56	6.84	Woman crying	3.65	5.33
	Toxic waste	3.72	5.24			
	Waste	3.81	4.47			
	Crying woman	2.25	5.34			
	Hospital	1.95	4.53			
	Sick man	4.14	3.41			
	Injury	2.54	5.92			
Fear	Hospital table	2.49	5.52	Monster growl	3.37	6.39
	Blood	2.07	6.06	Glass break	3.22	6.23
	Dead body	1.83	6.36	Woman scream	1.93	7.77
Anger	Smoke	2.8	4.26	Cough	2.46	5.87
	Mud	3.01	4.82	Alarm	2.95	6.98
				Error sound	2.42	7.98
				Ambulance	1.85	7.72
Disgust	Roaches	3.19	5.37	Bees	2.16	7.03
	Rat	3.66	4.93	Buzzing	3.02	6.51
	Dirty	2.26	6	Vomit	2.08	6.59
	Vomit	1.89	6.01	Toilet	4.68	4.03
	Bathroom	5.75	3.56			
	Roach on pizza	2.46	5.88			
	Dirty	2.26	6			
	Mud	3.01	4.82			
	Garbage	3.8	4.17			
	Toilets	2.32	5.58			

through neural networks or other classifiers suitably trained to recognize them. However, due to the type of experimental set-up envisaged (projected wall), it was impossible to acquire the face accurately enough to capture facial expressions. For these reasons, despite some criticisms in the literature [89], the first method has been privileged in this work. All measures were implemented on Qualtrics XM and collected using a 10" tablet (Apple iPad).

5.2.1. Empathy and Alexithymia

Before taking part in the study, participants were asked to fill in two questionnaires that aimed to assess their empathy level and the alexithymia dimension, which is defined as a cognitive deficit related to the processing of emotional information or as a deficit of affect regulation that ranges on a continuum [118]. For the empathy assessment, we used an Italian translated and validated version of the Balanced Emotional Empathy Scale (BEES) [71], while for the assessment of alexithymia, we used a validated Italian translation of the TAS-20 [19].

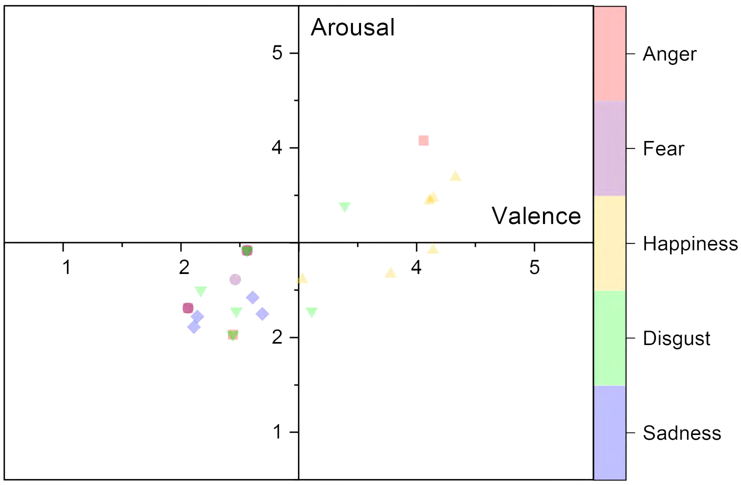

Figure 8: Distribution of main colors used in the scenarios based on valence-arousal rates based on [116].

5.2.2. SAM

We used a digital version of the SAM questionnaire [15] constituted by three pictorial 9-point scales related to valence, arousal, and dominance. As Mehrabian and Russel's bipolar dimensions, here valence ranges from the lowest unpleasant value represented by a frowning figure to the highest pleasant value represented by a smiling figure. The same mechanism is followed for arousal rates, which in the SAM implementation ranges from the lowest arousal value, represented by a sleepy figure, to the highest arousal value represented by a wide-eyed figure. Finally, the dominance dimension is represented in the SAM by changing the figure size, where the biggest figure corresponds to the higher perceived control over the feeling and the situation.

A pictographic scale has been chosen for the self-assessment because it aims to be more intuitive than a purely text-based scale and more precise than a discrete scale. Some pictographic scales have been developed in the last years, such as the Pick-A-Mood (PAM) [33] and the recent Morph-A-Mood (MAM) [56]; nonetheless, authors opted for the SAM to guarantee the compliance in the assessment evaluation, since also the IAPS and the GAPED databases involved in the study have been validated using SAM.

Even if the adoption of a pictographic scale has been picked precisely with the purpose of maximizing the spontaneity of participants' self-assessment, an explanation followed by a first session of training has been provided to ensure the coherence of the answers with the actual emotion felt by the user.

5.3. Procedure

Before starting the scenario presentation, participants were requested to read and sign a consent form. They were then asked to sit on a fixed chair located in front of a wall screen (width 3; height 2.5 meters) at a distance of 2 meters from the projected wall. Then, participants were given oral instructions and subsequently given the tablet on which the structure of the study and the composition of the questionnaire were explained again. After the explanation, they were asked to give a first assessment of their current emotional state on valence, arousal, and dominance dimensions, which constituted our baseline. We then gave them a mouse and a keyboard and proceeded with a brief training session on a simple virtual environment developed with Unity Software (version 2019.4.13), constituted by a plane and some geometric 3D obstacle. Participants controlled their movements with WASD keys and oriented their point of view with the mouse. When they felt confident with the controls, participants communicated that they could start the exploration session, in which they were asked to navigate and explore 7 scenarios, one for each discrete emotion used to categorized our VEs, plus two scenarios not considered in the current work. Each scenario had a fixed duration of 90 seconds, and they were projected using an Optoma projector (model EH503; resolution 1920x1080p; framerate 60 fps) connected to a PC (GPU NVIDIA GTX 2070 Max-Q; CPU Intel i7; RAM 32 GB). The audio was played through over-ear headphones (AKG-K240) connected to the PC. The selection of one of the two scenarios for each condition, as well as conditions order, was counterbalanced between participants using a Latin square design. After each scenario, participants were asked to rate the SAM scales and to complete other measures not considered in the current paper.

The assessment phase between the presentation of the scenarios lasted 5 minutes on average and this break, combined with the counterbalanced order of the scenarios, helped us to counteract possible emotional bias between different conditions. The entire experimental session lasted about 45 minutes.

6. Results

For the empathy and alexithymia scores, we performed mixed repeated measures ANOVAs with our experimental conditions as within-subjects factor, SAM dimensions as measures and the questionnaire score as a between-subjects variable. Regarding SAM rates, two normality tests (i.e. Kolmogorov–Smirnov, Shapiro-Wilk) were carried out to determine if data were normally distributed. They did not follow a normal distribution, so we decided to proceed by using a non-parametric Friedman test analysis of differences among repeated measures. Then, a post hoc analysis with Wilcoxon signed-rank test was conducted. Since multiple comparisons increase the probability to commit Type I errors, a Bonferroni correction was applied to lower the critical p-value depending on the number of tests performed. We had 8 conditions (including baseline and the two additional scenarios) resulting in 28 (=8x7/2) [N(N-1)/2] possible combination, therefore we adjusted the significance level to 0.002 (= 0.05/28) [21]. A power analysis to estimate sample size was performed using G*Power. Approximately 45 participants are required for a Wilcoxon signed-rank test to obtain a power of 0.95, an alpha level of 0.05, and a medium effect size (d = 0.5) [38, 59].

6.1. Empathy and Alexithymia

We collected forthy three responses to the BEES and TAS-20 questionnaires (five participants did not complete them and were excluded from the analysis). Empathy scores were classified into three different categories: above, below, and corresponding to the average of the population in which the questionnaires were validated. TAS-20 scores were classified as above the average (i.e. higher level of alexithymia), borderline, and corresponding to the average. For the empathy assessment (BEES), 19 participants obtained a lower score than the mean of the population. Regarding the alexithymia assessment (TAS-20), only two participants obtained a result that fell outside the average score, while 14 participants fell into the borderline category.

Empathy: There was a significant interaction between the valence rates reported in our scenarios and the score obtained at the BEES questionnaire [$F(7.971) = 2.569$; $p = 0.012$; $\eta_p^2 = 0.116$]. Pairwise comparisons (Bonferroni corrected) showed that, in the Anger scenarios, those subjects with empathy levels lower than the average reported significantly higher levels of valence ($M = 5.16$; $SD = 1.3$) than those with higher than average ($M = 2.5$; $SD = 1.97$) empathy level. A similar trend was visible in the Disgust scenarios, where participants with an empathy level lower than the average reported more positive valence rates ($M = 4.84$; $SD = 1.89$) than those with a higher empathy level ($M = 2.67$; $SD = 1.63$). No significant interaction was found between the empathy assessment score and the arousal dimension [$F(7.445) = 0.706$; $p > 0.05$; $\eta_p^2 = 0.035$], or the dominance dimension [$F(10.378) = 1.234$; $p > 0.05$; $\eta_p^2 =$ 0.060].

Alexithymia: results did not show a significant interaction effect of TAS-20 scores with the three SAM dimensions (valence: $F(7.304) = 0.462$; $p > 0.05$; $\eta_p^2 = 0.023$; arousal $F(7.437) = 0.796$; $p > 0.05$; $\eta_p^2 = 0.039$; dominance $F(10.035)$ $= 0.935$; $p > 0.05$; $\eta_p^2 = 0.046$).

6.2. SAM rates

The results showed a statistically significant difference depending on which scenario was presented plus the initial baseline for valence [$\chi^2(7) = 198.390$; $p = < 0.001$], arousal [$\chi^2(7) = 150.656$; $p = < 0.001$], and dominance [$\chi^2(7) =$ 175.892; $p = < 0.001$]. Table 3 shows descriptive statistics concerning SAM rates for each condition, while Figure 10 shows the distribution of our VEs based on valence and arousal rates.

6.2.1. Valence

Post hoc comparisons defined a clear distinction between the group constituted by the Baseline ($Mdn = 6.50$) and the Happiness condition ($Mdn = 7.00$), and the group of *"negative conditions"* constituted by Sadness ($Mdn = 4.00$), Anger ($Mdn = 4.00$), Fear ($Mdn = 4.00$) and Disgust ($Mdn = 4.00$) conditions. As shown in Table 4, the Baseline and the Happiness condition differed significantly ($p < 0.001$) from the group of *"negative conditions"*. The two groups identified showed good internal consistency, especially for the negative emotions, while an almost critical p-value was

Table 3
Descriptive statistics of SAM ratings.

	Valence			Arousal			Dominance		
Condition	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*
Baseline	6.50	6.00	1.130	3.60	3,50	1.865	6.21	6.00	1.675
Happiness	7.08	7.00	1.442	3.42	3.00	2.201	7.19	8.00	1.758
Sadness	3.88	4.00	1.975	4.73	5.00	2,141	4.90	5.00	2.126
Fear	3.98	4.00	2,099	6.71	7,00	1,913	3.83	3.00	2.400
Anger	4.13	4.00	1.782	5.56	6.00	1.978	2.96	2.00	1.967
Disgust	4.15	4.00	1.868	4.56	5.00	2.113	5.54	5.50	2.202

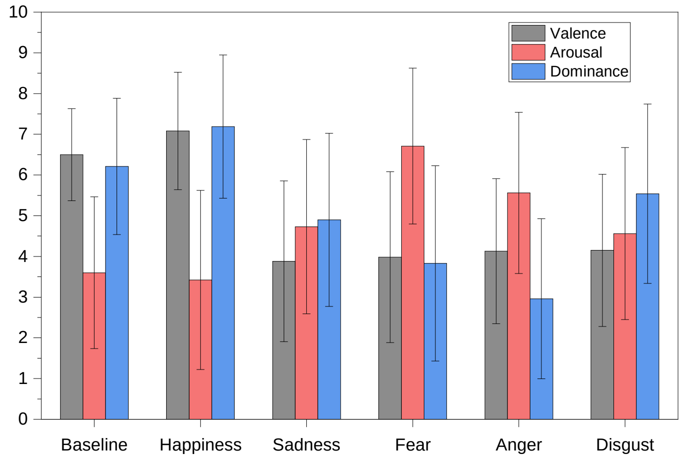

Figure 9: SAM rates for our experimental conditions.

Table 4
Post hoc comparison for valence rates

	Happiness	**Sadness**	**Anger**	**Fear**	**Disgust**
	Z	*Z*	*Z*	*Z*	*Z*
Baseline	-3.030	-5.092**	-5.627**	-5.070**	-5.160**
Happiness		-5.728**	-5.932**	-5.472**	-5.730**
Sadness			-1.124	-0.864	-1.778
Anger				-.0200	-0.201
Fear					-0.681

$^{*}p = 0.001$
$^{**}p < 0.001$

reported between the Baseline and the Happiness condition (Z = -3.030; p = 0.002). All comparisons for valence rates are reported in Table 4.

6.2.2. Arousal

Post hoc comparisons showed that Anger (*Mdn*= 6.00; Z = -4.570; $p < 0.001$) and Fear (*Mdn* = 7.00; Z = -5.599; $p < 0.001$) conditions differed significantly from the Baseline (*Mdn* = 3.50), while results did not show significant differences from the Baseline for the Happiness (*Mdn* = 3.00), Sadness (*Mdn* = 5.00; Z = -3.142; p = 0.002), and Disgust (*Mdn* = 5.00; Z = -3.002; p = 0.003) conditions, as it happened between the Sadness and Disgust

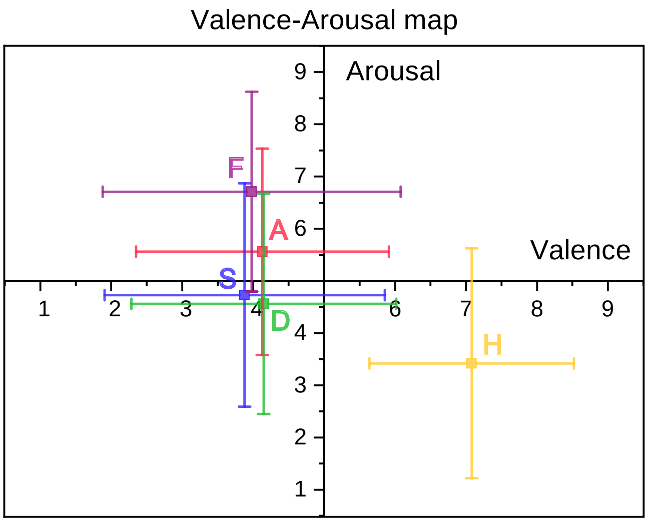

Figure 10: Distribution of our VEs based on valence and arousal rates.

Table 5
Post hoc comparison for arousal rates

Condition	Happiness	Sadness	Anger	Fear	Disgust
	Z	*Z*	*Z*	*Z*	*Z*
Baseline	-0.562	-3.142	-4.570**	-5.599**	-3.002
Happiness		-3.219*	-4.200**	-4.955**	-3.011
Sadness			-2.756	-4.996**	-0.485
Anger				-4.314**	-3.391*
Fear					-5.146**

*$p = 0.001$
**$p < 0.001$

conditions (Z = -0.485; p = 0.628). The most activating condition was represented by the Fear scenarios (*Mdn* = 7.00), which significantly differed from all the other conditions, while the Anger condition (*Mdn* = 6.00) showed significant differences with all other conditions, expect for the Sadness condition (*Mdn* = 5.00; Z = -2.756; p = 0.006). The Happiness condition (*Mdn* 3.00) followed the same pattern shown for valence comparisons and differed significantly from the Sadness (*Mdn* = 5.00; Z = -3.219; p = 0.001), Anger (*Mdn* = 6.00; Z = -4.200; $p < 0.001$) and Fear (*Mdn* = 7.00; Z = -4.955; $p < 0.001$) conditions, but did not show significant differences from the Disgust condition (*Mdn* = 5.00; Z = -3.011; p = 0.003). The results are shown in Table 5.

6.2.3. Dominance

Post hoc comparisons showed that Anger (*Mdn* = 2.00; Z = -5.469; $p < 0.001$), and Fear (*Mdn* = 3.00; Z = -4.760; $p < 0.001$) conditions differed significantly from the Baseline (*Mdn* = 6.00). Dominance in the Happiness (*Mdn* = 8.00) condition was also significantly different ($p < 0.001$) from the Sadness (*Mdn* = 5.00), Anger (*Mdn* = 2.00), Fear (*Mdn* = 3.00) and Disgust (*Mdn* = 5.50) conditions. Results of the Wilkoxon Signed rank tests also showed significant differences between Anger and Sadness conditions (Z = -4.310; $p < 0.001$), Anger and Disgust conditions (Z = -4.905; $p < 0.001$), and Fear and Disgust conditions (Z = -4.218; $p < 0.001$). Results are shown in Table 6.

Table 6
Post hoc comparison for dominance rates

Condition	**Happiness**	**Sadness**	**Anger**	**Fear**	**Disgust**
	Z	Z	Z	Z	Z
Baseline	-3.035	-2.904	-5.469**	-4.760**	-2.117
Happiness		-4.652**	-5.721**	-5.648**	-4.026**
Sadness			-4.310**	-2.917	-1.670
Anger				-2.832	-4.905**
Fear					-4.218**

$^{*}p = 0.001$
$^{**}p < 0.001$

7. Discussion

In this study, we defined a methodology to design affective VEs. We considered a categorization based on five emotions (i.e., happiness, sadness, fear, anger, disgust), and we highlighted the different design elements able to characterize the emotional experience, including valence, arousal, and dominance. We then mapped the design elements in an affective space based on the two dimensions of valence and arousal (referring to the Circumplex Model of Affect, that uses these two dimensions). Because of the complexity and the subjectivity linked to the emotional process, two VEs were developed for each category in order to cover small variations of valence and arousal. Our methodology allowed us to elicit different emotional states, resulting in significant differences in the valence, arousal, and dominance dimensions and highlighting correspondences between these three dimensions and the five emotional categories considered. To check any possible bias due to empathy capacity, we assessed our participants using two validated scales (i.e. BEES and TAS-20). Results showed that the score obtained at the empathy assessment had a small effect only in the valence rates related to the anger and disgust scenarios, where participants with a lower empathy score rated more positively the experience. The results obtained correspond to our expectations, and Figure 10 shows that valence and arousal rates for our affective VEs overall matched the areas defined by the design elements considered in our methodology.

As expected, valence rates allowed us to identify a clear distinction between environments able to elicit positive affect (i.e., happiness condition) and those linked to negative affects (i.e., sadness, fear, anger, disgust). Nevertheless, this dimension did not highlight significant distinctions between the categories which constitute the group of negative affects and also failed to identify a distinction between the baseline and the happiness condition, even if the Wilcoxon signed-rank test showed an almost critical p-value. At a superficial view, arousal rates seem to follow a similar distinction between high and low activating experiences, but with an opposite pattern to valence, where scenarios associated with negative emotions were linked to higher arousal rates. However, a more detailed analysis highlighted the existence of significant differences also between scenarios that shared similar valence rates, especially for the negative ones. The most activating category was constituted by the fear scenarios, which was significantly distinct from all the other conditions. Similarly, anger scenarios obtained arousal rates significantly different from all the other scenario categories, except for the sadness condition. The arousal rates for the scenarios belonging to the disgust condition did not differ significantly from the sad condition and, interestingly, not even from the happy and baseline conditions. The low level of arousal obtained in the positive scenarios may be explained by our choice to include a happy and yet very relaxing environment, which may have contributed to reducing participants' activation. Nevertheless, obtaining highly arousing positive emotions seems to represent a harder task than for negative ones. For this reason, working on different levels of interaction between the presented design elements, and the introduction of additional sensory stimuli may be useful in increasing users' activation. Finally, also for dominance rates, it was possible to highlight a distinction that follows the one obtained between positive and negative emotions. Results seem to suggest the existence of a general pattern of lower perceived control in those scenarios characterized by negative emotions (i.e., sad, anger, fear, and disgust) compared to the baseline and the happy scenarios. Despite a somehow general discredit of the role of dominance and subsequent partial disuse of this dimension from the pleasure-arousal-dominance model, dominance has shown to have some credit in the experimentation, to foster engagement in the VEs and differentiate emotions.

Taken as a whole, these results support the use of our design methodology for the development of affective VEs to elicit distinct emotional responses. Rates obtained using SAM allowed us to clearly define our scenarios in terms of positive and negative valence and provided an even more detailed distinction in terms of activation. These differences constitute a further level of specification, identifying responses that corresponded to the specific emotional entities considered during the design process. Moreover, the testing of our scenarios included the collection of dominance rates, which offer an additional parameter for the characterization of the affective experience and completes the emotional framing from a valence-arousal-dominance model perspective. Further evidence of the efficacy of the VEs developed following the presented methodology is provided in [4].

Considering the possible applications of the described methodology, promising areas are linked to entertainment, education, but also work-related environments. Recently the term 'metaverse' has become popular among practitioners, investors, and researchers. Currently, the most popular business ideas linked to the metaverse are primarily commercial and entertainment, but the potential is enormous. As emotions play a fundamental role in real-life, it is straightforward to imagine that they will also play a role in the virtual or augmented life of the metaverse. Thus, the methodology described in this paper may represent a useful guideline for content creators and designers who want to add affective elements to their content and evoke particular emotions.

7.1. Limitations

Our Virtual Environments were tested using a semi-immersive technology. There is evidence in the literature that the use of more immersive devices can increase presence, which may enhance emotional responses. Moreover, the level of immersion, presence, agency, and body ownership can affect valence, arousal, and dominance. For instance, Kim et al. measured the emotional response, the level of presence, and simulator sickness in a virtual task performed in different VR systems (i.e., desktop, HMD, and CAVE systems). Their results revealed that CAVE and HMD obtained a higher level of presence, which corresponded to higher arousal rates. Considering valence, HMD elicited more negative affect than the desktop platform, unlike CAVE systems which elicited a more pleasant effect. Nevertheless, desktop systems evoked significantly less simulator sickness than CAVE and HMD technologies [54]. Considering these results, our affective Virtual Environments may prove even more effective when using more immersive technologies. Manipulating these features (e.g., using different devices, body avatars for the user, allowing different actions) would add relevant variables that should be considered in future work.

Another limitation of the present study might be the following: the results show that the desired emotions are effectively evoked by the environments, which does not necessarily imply that the design methodology itself works. In other words, the study results allow us to conclude that the VEs may relate closely to specific emotions, but there is no evidence in support of the design methodology. Anyway, a methodology is usually developed to make a design activity systematic, transferable, and repeatable. The above testing demonstrates that once the suitable elements to create a VE have been selected, the result is the one expected. In choosing the elements, we followed the described steps of the method, which makes the process systematic and repeatable. Although there are no methodologies to compare to verify that the one we propose is more or less effective, it remains true that the result is the expected one given the premises. This was confirmed on five distinct emotions and with two environments for emotion.

8. Conclusions and future work

In the current work, we presented a design methodology for the development of affective Virtual Environments that takes into account different aspects able to influence users' emotional experience. We considered different emotional theories in order to implement design elements that allowed a differentiation in the emotional states elicited. The design elements identified following our methodology, which also included the integration of contents from validated affective databases, was then tested on the three dimensions of valence, arousal and dominance.

For the development of the presented scenarios, we focused mainly on visual and auditory contents. The integration of additional sensory modalities is particularly challenging because of the difficulties related to the management and delivery of olfactory and tactile sensory stimuli. Future developments will try to include and evaluate also olfactory and tactile aspects.

Furthermore, future works may include new variables able to further differentiate the various scenarios. For instance, users' movement parameters have been kept constant in the scenarios presented in this paper, but different levels of freedom or speed may be explored in further investigation. Another aspect we did not investigate (partially due to the difficulty of using HMD devices during the COVID-19 pandemic) is the technology used to deliver stimuli. The same VE can be perceived differently, depending on the hardware device selected to render it to the user. Using Head-Mounted Displays is different from using a projected wall or a PC screen. This is not limited to visual tools: designing specific feedback for a haptic interface might not be perceived the same if the device changes. Moreover, combining different technologies together might not give the expected result and increases the combination of possible effects. This is true also considering the technology used for control, which includes various devices (controller, keyboards, mouse, sensors). To date, there's not a very well-known, comprehensive, and rigorous method of creating multisensory environments. In fact, the complexity of VR and human emotions, and the high number of variables and interaction between them, prevent this process from being straightforward. Future work will integrate all the mentioned aspects in progressively more complete methodologies.

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