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Collaborative immersive authoring tool for real-time creation of multisensory VR experiences

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Abstract
With the appearance of innovative virtual reality (VR) technologies, the need to create immersive content arose. Although there are already some non-immersive solutions to address immersive audio-visual content, there are no solutions that allow the creation of immersive multisensory content. This work proposes a novel architecture for a collaborative immersive tool that allows the creation of multisensory VR experiences in real-time, thus promoting the expeditious development, adoption, and use of immersive systems and enabling the building of custom-solutions that can be used in an intuitive manner to support organizations' business initiatives. To validate the presented proposal, two approaches for the authoring tools (Desktop interface and Immersive interface) were subjected to a set of tests and evaluations consisting of a usability study that demonstrated not only the participants' acceptance of the authoring tool but also the importance of using immersive interfaces for the creation of such VR experiences.

Keywords Collaborative · Multisensory · Virtual reality · Real-time · Authoring tool

1 Introduction

When one refers to immersive systems, Virtual Reality (VR) is a key concept; one of its main goals is to transport users to virtual spaces and create the feeling of "being there" as if they were in a real environment [38, 45]. To do this, VR offers advanced user interfaces that involve the user in a virtual environment (VE) in which he can interact through different sensorial channels [9]. Consequently, as the number of senses being stimulated increases and immersiveness grows, the user experience becomes more engaging and successful; hence

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there is a direct relationship between a multisensory VR system's quality and efficiency and experiential results [13, 16, 44].

Despite the widespread use of VR across a variety of fields such as architecture [39], cultural heritage preservation [33], medicine [2, 25, 43], military, education [22, 38], and entertainment [30, 36], the majority of VR applications rely essentially on audio and video stimuli supported by desktop-like setups that do not allow to fully exploit all known VR benefits. Additionally, it is well-known that the creation of VR applications requires considerable resources and expensive technology that must be combined through the use of complex authoring tools. Consequently, there are substantial barriers not only to creating multisensory VR experiences but also to the much-needed collaborative work between all the involved stakeholders [6, 42]. Hence, in addition to creating and distributing multisensory VR applications, it is of utmost importance to develop mechanisms that allow for the expeditious creation of multisensory VR experiences in a collaborative manner.

To overcome the current gap, we present a proposal for a collaborative and immersive authoring tool for the expeditious creation of multisensory VR experiences with a high degree of customization; the tool enables the fast prototyping of multisensory VR applications to any application field. The novel approach presented here has a collaborative dimension that will bring competitive advantages to businesses that adopt this type of solution. An evaluation procedure for the proposed tool is presented as well. This evaluation includes two different interaction metaphors (desktop and immersive interfaces) with the goal of determining which approach is more suitable for such an innovative authoring tool.

The remainder of this paper begins with a background characterization section in which all the inherent conceptual constructs are analysed, followed by a section in which the proposed tool is described extensively. This is followed by a description of the evaluation procedure performed on the tool to verify its adequacy and efficiency. Next, we discuss implications associated with the present research. Finally, we present our conclusions and final acknowledgements.

2 Background characterization

As previously mentioned, VR attempts to transport users to a virtual space and create a sense of presence ("being there") as if they were in a real environment. Bearing this in mind, one can say VR is based upon two principal concepts: Presence and Immersion. Presence can be viewed as a state of consciousness based on the sense of being in the VE; Immersion is more related to the technological aspect of the VR system and the extent to which the technology is capable of isolating the user from the real world, deceiving their sensations and engaging users with the VE [45].

Virtual reality can be broadly divided into three categories according to the sense of presence and/or immersion that they can develop based on the system apparatus: non-immersive, semi-immersive VR, and fully immersive VR [34]. Non-immersive systems are based on desktop PCs to deliver the VR experience and on mice, keyboards and joysticks to interact with the system; semi-immersive systems make use of large displays to present the VE and have joysticks, trackballs and data gloves as input devices; fully immersive VR systems use Cave Automatic Virtual Environments (CAVEs) and Head Mount Displays (HMDs) to present the VR content with which the user can interact using voice commands or specific controllers.

Due to its nature, VR has been successfully used in a variety of application fields such as architecture, cultural heritage preservation, medical training, military simulation and training, education and entertainment. In architecture, for example, VR enables creating virtual spaces that can be explored by designers and clients to have a realistic preview and more informed discussions about a design project [39]. In cultural heritage, it is possible to reconstruct virtual historical spaces or digitally restore the original appearances, resulting in a digital preservation of cultural assets [33]. In medicine, VR has been very valuable in the training of surgical procedures, as it improves the performance of the medical teams [2, 19, 25, 43]. The education field has taken advantage of VR applications through the simulation of virtual learning spaces in which users are led to problem-solving, data interpretation or even new content through serious games that they play while being presented with pedagogical content with the purpose of retaining knowledge [22, 37]. In entertainment, there is the example of the gaming industry; VR is very significant as the gaming market is based on it [30].

2.1 Multisensory virtual reality

Humans perceive the real world through the simultaneous interaction of their senses with the surrounding environment. Therefore, to successfully transport a user to a VE, it is expected that the more senses that are stimulated coherently, the better the experience and, consequently, the effectiveness of the VR application [13, 16, 18, 44]. In fact, multisensory VR has been addressed since the 60s [20], and despite its significance to the scientific community, there has been no continuity in the work due to the constraints and high costs of its associated technology. However, technology has evolved to a point at which it is possible to put forward valid multisensory VR experiences, motivating some advances in this field as listed in Table 1. Nevertheless, multisensory VR experiences are mainly custom-built and thus very demanding, complex and costly to develop because there are no authoring tools widely available.

As one can verify in Table 1, there have been very valuable contributions in multisensory VR applications that benefit a variety of application areas. Nevertheless, there is a limitation that can compromise the wide deployment of multisensory VR experiences: all these

Table 1 Pertinent work in multisensory VR

Author	Topic	Contribution
Seymour et al. [43]	Using VR to improve Operating Room performance	Demonstrates that it is possible to transfer knowledge from VR to the Real World
Pan et al. [37]	Learning using VR	Reviews different approaches to learning using VR
Iwata et al. [25]	Using VR to train surgeries	A system that allows trainees to gain experience in different surgery techniques
Luigi et al. [28]	Validation of Immersive VR environments	Evaluates if VR has the same effect as Real Environments
Feng et al. [16]	Feedback improves performance	Studies the influence of Footstep vibration in performance
Manghisi et al. [29]	Multisensory tour through the south of Italy	A system that allows the participants to experience a multisensory tour
McGregor [32]	Using multisensory feedback for tactical training	A system that can evaluate individual resilience in tactical training
Arnold et al. [4]	Edible Interactions in VR	Uses edible objects to interact with the VE
Jones et al. [26]	Multisensory system for VR experiments	Patent of a system that can release various stimuli

applications were built from scratch, and they are closed solutions, meaning that there are no authoring options for others to use as a basis for developing similar applications.

2.2 Authoring tools for multisensory VR experiences

When creating Multisensory VR experiences, one does not simply add stimuli to the VE: it is critical to ensure a credible stimulation of the different senses [7]. In fact, if not done properly, multisensory stimulation can compromise the entire VR experience and have a negative impact on users, as it can impose an extra cognitive load [12]. Thus, when creating VR experiences, the Content Creator should take several factors into account to create an optimal VR experience that has no negative impact on users such as cybersickness or associated symptoms that can actually discourage the use of this technology [31].

Due to the specificities of VR applications, it is usual to use game engines as authoring tools for VR experiences because they provide an Integrated Development Environment (IDE) that allows full creation of VEs and interaction mechanisms. Examples of popular game engines used for this purpose are Unity [46], Unreal [15] and CryEngine [11]. These game engines provide useful mechanisms for the development of VR solutions because they allow, for example, to import assets and scripts from the community, collaborative development and multi-platform portability, and they have integrated physics and rendering engines.

Despite the possibility of using these tools for authoring immersive and/or multisensory VR experiences, they were not specifically designed for this purpose. In fact, to the best of our knowledge, the literature is scarce in this field, and the only efforts of which we are aware in the field are the DIY World Builder [48], the multisensory authoring tool proposed by Freitas et al. [17], the Adobe Creative Cloud tools [1], and the immersive system for multisensory 360 videos [10]. The DIY World Builder consists of an immersive setup that allows building multisensory VEs from a first-person point-of-view. The concept is to have the user in an empty space and give him the possibility of adding and editing objects and applying textures and lighting effects based on a predefined library [47]. From the perspective of authoring tools for the development of customized VR experiences, one of the limitations is that the user is limited to a predefined virtual space that is fixed and to a predefined library of assets (Fig. 1).

A step forward in multisensory VR content creation was the system for the management and visualization of multisensorial contents proposed by Freitas et al. [17] that allows users to create immersive multisensory experiences based on 360 video. Essentially, the users import a 360 video into the system and have the possibility of adding wind, smell and force feedback to the 360 video. Stimulus delivery can be further customized in terms of timing and intensity.

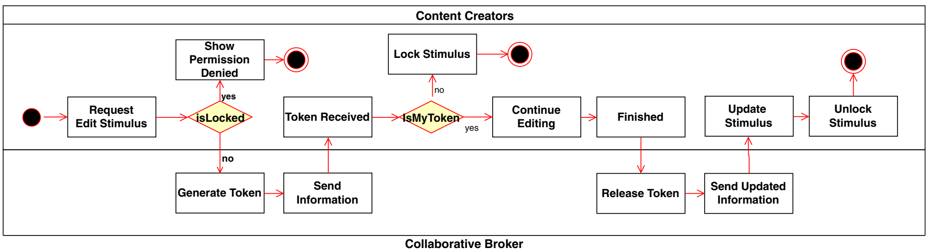

Fig. 1 Collaborative feature workflow

The system has a desktop interface, but once the experience is created, the users can experience it using HMDs. Its authors evaluated the system and obtained positive feedback from users regarding ease of use and acceptability.

The widespread popularity of immersive VR has additionally awakened the interest of important companies such as Adobe, which released an immersive interface for 360 video in a recent update of Adobe Creative Cloud. It is possible, for example, to configure the camera position, effects, audio or stitching [1]. However, this work was limited to 360 videos and no multisensory stimulus was addressed.

As for immersive content, Coelho et al. [10] proposed an authoring tool in which one can create an immersive multisensory VR experiment using a desktop application with the possibility of playing the experiment in VR. The only negative aspect is that it, also, is based on 360 videos, similar to the approach proposed by Freitas et al. [17]. Both approaches are similar, but the authoring tool proposed by Coelho et al. allows the possibility of previewing the creation of the multisensory VR experience 'in loco'. This work was the inspiration of the present work, in which we propose to take a step forward and extend this proposal not only to support both 360 videos and VEs, but to contemplate different interaction metaphors as well to provide an optimized user experience. The advantage of this type of application is that it expedites the process of creating immersive multisensory content, with real-time calibration of the stimuli, creating a "what you see is what you get (WYSWYG)" experience. Having an immersive interface enables Content Creators to have a more control as they have the perception as to where different stimulus is positioned in space whereas in a conventional desktop setup Content Creators only have a panorama preview of the environment that does not facilitate such spatial awareness. On the other hand, the disadvantage of these previous efforts (desktop application) is that they do not allow collaboration between Content Creators and that is what the present work endeavours to mitigate such issues, adding a real-time collaborative dimension to the immersive authoring tools for the real-time creation of multisensory VR experiences. This is useful because multisensory VR experiences might require multiple features that are produced by different professionals, and a collaborative feature will enable to the entire team to work simultaneously. This will both result in a competitive advantage to organizations and will promote the adoption and use of this type of immersive authoring tool.

3 Collaborative immersive authoring tool for real time creation of multisensory VR experiences

To the propose an immersive system for the expeditious creation of immersive multisensory VR experiences, we performed a system requirements analysis to identify the core features to be included in such an authoring tool that should itself be immersive. For a more informed architecture proposal as well as for a planned development based on a reflection-action methodology, we used the authoring tool proposed by Coelho et al. [10] as a reference. Thus, we defined a set of functional and non-functional requirements with the main goal of having a collaborative multisensory VR authoring tool that supports various stimuli: sound, haptic feedback and smell. Due to the novelty of the proposal, two different implementations of the proposed system with different interaction metaphors (Desktop and Immersive interfaces) were developed to determine which approach is more adequate.

3.1 System architecture

From a functional perspective, the authoring tool should allow the user to create a new project or load an existing project. The multisensory VR experience can be based on either a virtual space or a 360 video and should allow Content Creators to add/edit different stimuli to the project and to customize their durations and timing. The preview of the VR experience being created should be available in real-time with the possibility of using conventional display or an HMD as display device; added stimuli should be presented as well when previewing the experience. For this, the authoring tool should support the basic functions of a video player such as play, pause or restart. Lastly, the authoring tool should support collaborative creation/editing of multisensory VR experiences. For non-functional aspects, our goal is to put forward an authoring tool that is intuitive and easy to use. To ensure a proper multisensory delivery, the authoring tool must communicate effectively with the output devices.

Bearing the above in mind, we conceptualized a collaborative authoring tool whose architecture is illustrated in Fig. 2. The collaborative authoring tool is supported by the Collaborative Broker (CB) that mediates all the actions made by multiple Content Creators as well as it is responsible for ensuring the proper storage of the authored content. The CB controls all the actions of multiple Content Creators through a synchronization layer that is responsible for handling the actions performed by the Content Creators, the virtual content and the technological components that are responsible for delivering the different stimuli. This synchronization layer is responsible for monitoring, for instance, which elements of the virtual world are being added/edited and to manage multiple editing in real-time. Different virtual elements can be edited simultaneously in real-time by different Content Creators. However, one challenge of real-time collaborative editing is that the simultaneous editing of the same

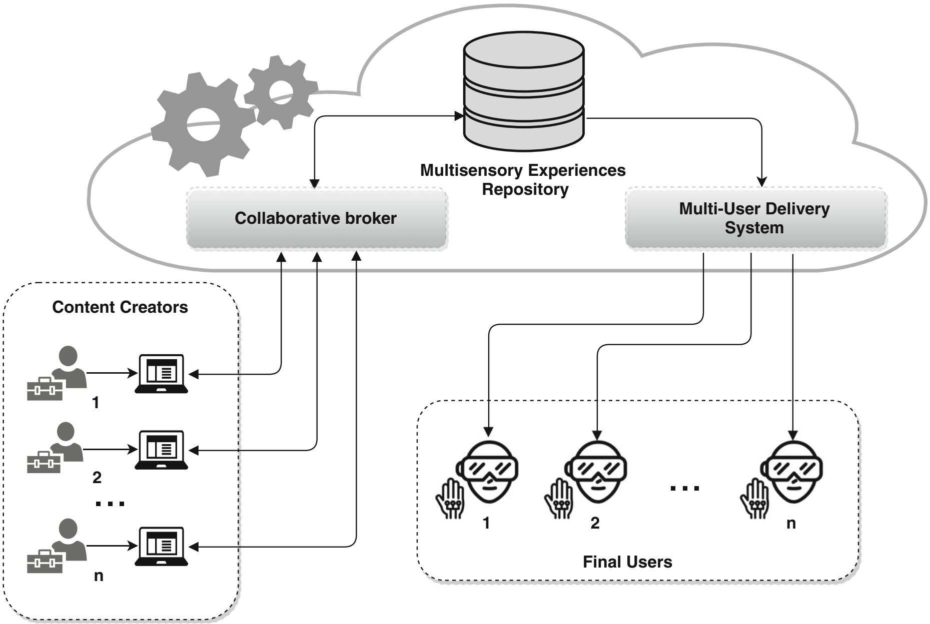

Fig. 2 Global architecture of the collaborative immersive authoring tool for real-time creation of multisensory VR experiences

virtual element could result in "versioning" conflict due to communications latency and availability of the technological devices that deliver the stimuli. To overcome such issues, the proposed architecture implements a token system where, when a virtual element is being added/edited it is attributed a token to the Content Creator that is performing the task and that temporarily blocks the virtual element similar to a semaphore operation in an OS, illustrated in Fig. 1. To ensure a good performance across different setups, and according to the suggestions made in [23, 40], the CB is designed to be modular and flexible allowing Content Creators to configure the different stimuli modules and to deactivate a given module if required. The CB is also responsible for the management and storage of all the data associated with each VR experience in the Multisensory Experiences Repository. All the stored VR experiences can be later accessed by Content Creators or Final Users. As for Content Creators, they can load existing VR experiences to further work on them. If a Final User accesses the experiment, a Multi-User Delivery System mediates the access allowing single or multi-user access to the multisensory VR experience.

From a user perspective (see Fig. 3), there are two applications available: the Authoring Tool and the Multisensory VR player. The Authoring Tools are designed for Content Creators to create multisensory VR experiences through a GUI that allows adding and configuring the different stimuli that make up the final multisensory VR experience with the possibility of previewing the experience "in-loco". The real-time-preview feature benefits this proposal as, in contrast to other proposals, it allows a better fine-tuning of the experience in real-time. When the Content Creator concludes the editing the project, he can save the experience for later access by him for revisions or by the Final User. The collaborative authoring tasks, as well as the multi-user features, are managed by the multisensory VR framework that ensures

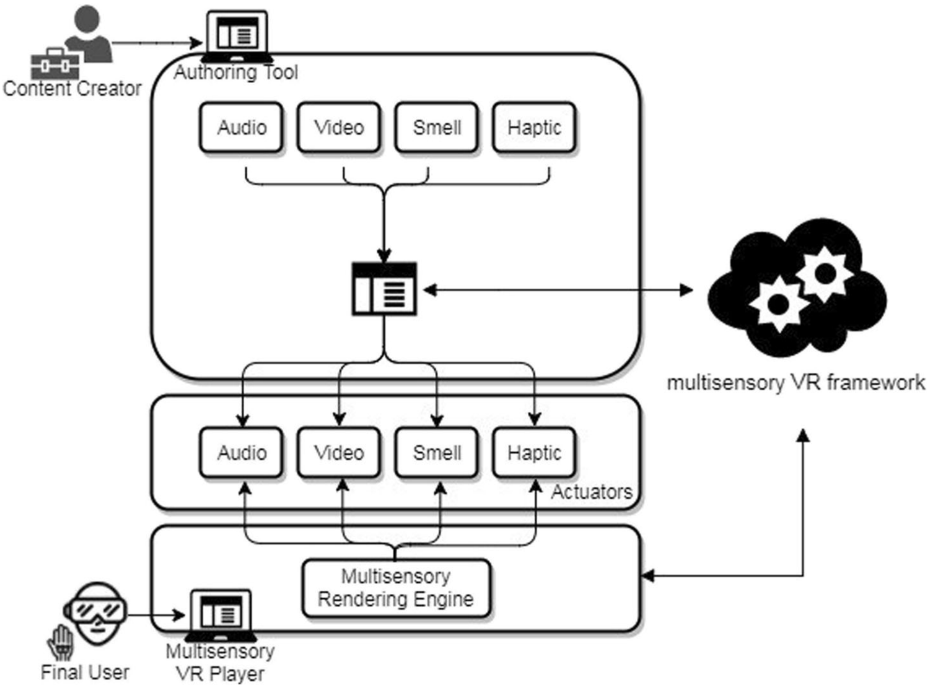

Fig. 3 Authoring tool and Multisensory VR player schema

the proper functioning of the whole system. Both the authoring tool and the multisensory VR player are responsible for communicating with the actuators (pieces of hardware that deliver the different stimuli) according to the brokers in the multisensory VR framework. The delivery of the different stimuli is mediated by the multisensory rendering engine, which communicates with the actuators and ensures the proper delivery of stimuli.

To guide the development of the proposed architecture, we created six main classes: Project, Video, Audio, Wind, Smell, Transducer. There is only one instance of the class Project and one instance of the class Video; there can be any number of instances of Audio, Wind, Smell and Transducers. Each instance knows its start and end times, how to communicate with the respective actuators and how to save itself to an XML file.

3.2 Authoring tools prototypes

Based on the specified architecture and due to its novelty, two prototypes were developed as proof of concept. The two prototypes differ in the interaction metaphor (desktop and immersive interface) and were implemented to evaluate not only the feasibility of the proposed authoring tool but also to determine which approach is more suitable to create immersive multisensory VR experiences. We theorized that an immersive interface would benefit not only the user experience but also the authoring process, as it would enable Content Creators to have a real view of the VE while composing the scene. We used the game engine Unity for development of the prototypes because, of the identified tools, it was the one with which the research team was more familiar. Additionally, it was the tool that seemed most capable of implementing the previously defined requirements. As these prototypes were proof of concept, support for VEs and collaborative features were not considered at this stage.

Desktop interface: the setup for this interface is non-immersive; the user has a keyboard and mouse as input devices. As Fig. 4 illustrates, the authoring tool allows the Content Creator to

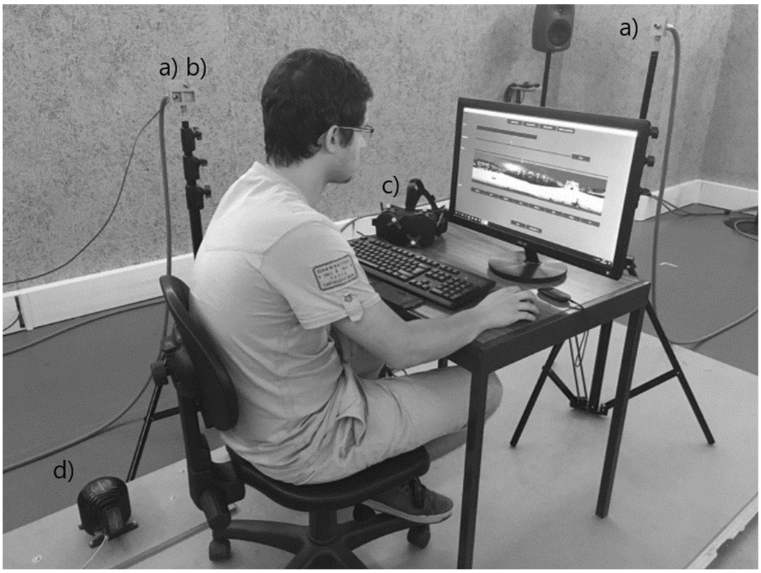

Fig. 4 Photo of a Content Creator using the 2D authoring tool: a) refers to the wind channels, b) to the smell dispenser, c) to the HMD, and d) to the haptic device that provides force feedback

see the video frame selected and all the stimuli of the scene. As defined, the authoring tool allows the Content Creator to edit/remove and change the start and end time of each stimulus. The Content Creator can also name and define the intensity and direction (if applicable) of the stimuli. The Content Creator can preview each stimulus or the VR experience as a whole at any time. The VR experience can be previewed both in the display or using HMDs.

Immersive interface: this interface has the desktop interface as starting point, so the core programme is still the same. The main difference is, obviously, at the interface level: in this version the setup is immersive (an HMD is used) and the interaction is based on point-and-click options (Fig. 5, top) and sliders for adjusting values (Fig. 5, bottom).

4 Usability evaluation

To evaluate the degree to which the proposed architecture could be implemented and used, a usability evaluation study was conducted including the two proposed prototypes. The research team hypothesized that despite desktop interfaces being widely used, an immersive interface would bring more benefits both in user experience and quality of the developed content because the Content Creator could have a real feel of the immersive experience being created instead of imagining the VE in a desktop interface.

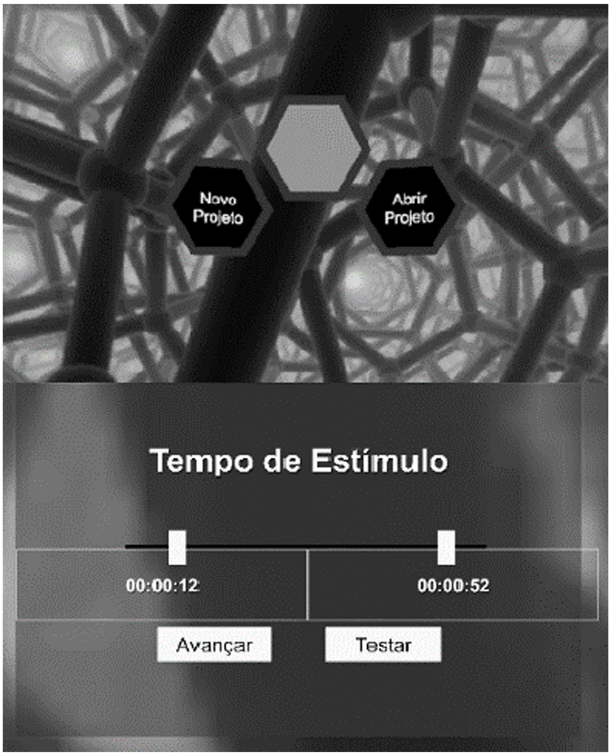

Fig. 5 Graphical User Interface (GUI) of the immersive interface

4.1 Sample

The sample of the evaluation study of the multisensory VR authoring tool prototypes consisted of 32 participants (16 males and 16 females) that were equally distributed between both prototypes. The participants were between 19 and 47 years old (M = 24.81, SD = 6.660), and all reported normal or corrected-to-normal vision. The demographic questionnaire showed that in terms of technology knowledge, 6.5% of all participants had low knowledge, 21.8% reported medium knowledge, 56.2% reported high knowledge and 15.5% reported excellent knowledge. In terms of knowledge about VR, 46.8% showed that had low knowledge, 25% reported medium knowledge, 18.7% high knowledge and 9.5% reported excellent knowledge.

4.2 Materials

As the evaluation consisted of a usability study, a test protocol was defined with a set of tasks to properly assess the interfaces and all their functionalities (Appendix). A socio-demographic questionnaire was applied to gather information about the sample. As the study is based on a usability evaluation, we adopted the System Usability Scale (SUS) [8] for overall system usability and the After-Scenario Questionnaire (ASQ) [27] for evaluating user satisfaction. The SUS scale consists of a 10-item questionnaire and, according to the scores, the system is classified as a recommendable usable system or a system with serious usability weaknesses that must be corrected. The ASQ is a 3-item questionnaire that assesses usability satisfaction. The two prototypes (Desktop interface and Immersive interface) were also part of the materials.

4.3 Apparatus

All the experimental studies were run on a desktop computer with the following configuration: Intel i7-6700 K CPU, NVIDIA 1080 GPU, 32 GB of RAM, and Windows 10. Depending on the interface being evaluated, the display was an ASUS VX248H 24” FHD display (for the desktop interface) or an HTC VIVE HMD (for the immersive interface) that allowed tracking of the position of the head. The HTC VIVE was used together with the respective controllers that allow tracking the hand as well as the possibility of interacting with the VE.

As actuators for the delivery of the different stimuli, the following equipment was used:

- Sound: Bose QuietComfort 25 headphones that feature active noise cancellation;
- Smell: Sensory Co SmX-4D, a professional solution that allows to deliver up to three different aromas in a fully customized manner;
- Haptics: Buttkicker LFE Kit for providing force feedback and a wind simulator created by the research team that allowed to control the wind intensity, duration and direction.

4.4 Variables

Two independent variables were defined in this study: Gender (Male and Female) and Interface (Desktop and Immersive interfaces). The Gender variable was included because it is known that it can have an impact on performance in VR applications [38, 45].

The dependent variables were: system usability (measured with SUS), effectiveness (complete the protocol successfully, number of errors, and number of help requests), efficiency (time spent to complete the protocol, expected to be 5 to 10 min to perform the experimental protocol), satisfaction (using the ASQ).

4.5 Hypothesis

Based on the defined variables, the null hypotheses were as follows:

H1. There are no statistically significant differences between Genders regarding Usability;
H2. There are no statistically significant differences between Genders regarding effectiveness, efficiency and satisfaction;
H3. There are no statistically significant differences across Interfaces regarding Usability;
H4. There are no statistically significant differences across Interfaces regarding effectiveness, efficiency and satisfaction;

4.6 Procedure

The evaluation study took place in a laboratory environment in which the research team had full control over room temperature (kept at approximately 21 °C), noise (the room has acoustic treatment and the experiments were conducted in a silent environment without external sources of sound to avoid distraction), and lighting levels (a light level of 500 lx was provided as it is recommended for a laboratory environment). The first step consisted of receiving the participant, giving a short briefing about the context of his visit and asking him to answer a sociodemographic questionnaire. It was then explained to the participant how he would participate in the experimental study without revealing the purpose of the study to avoid bias. Next, the participant was brought to the experimental apparatus that was previously arranged according to the interaction metaphor to be evaluated. The experiment consisted of two phases: a habituation scenario to get the participant familiar with the interface and to clarify possible doubts regarding interactions with it, and the execution of the previously defined test protocol that led the participant to perform a set of tasks that required using all of the functionalities of the developed systems. The participant was informed that a member of the research team would be with him in the experimental room throughout the experiment and that, at any time, he could request help if he had some doubt on difficulty in the execution of the defined tasks. Through direct observation, the researcher registered the duration of the experimental protocol execution, the number of help requests, and the number of errors committed.

After completion of the test protocol, the participant was asked to fill in the SUS and ASQ questionnaires. Finally, a debriefing was conducted to gather more information about the VR experience and general feedback.

4.7 Results

First, the normal distribution of the data was verified using Skewness and Kurtosis. This preliminary analysis revealed a normal distribution (|Skewness| < 2 and |Kurtosis| < 2) with no outliers ($N = 32$) except for the dependent variables Number of Errors and Number of Help Requests. Thus, in the variables where the data are normally distributed, we adopted the parametric Independent T-Test, and in the remaining data the non-parametric Mann-Whitney U tests were performed. Significant differences.

4.7.1 Gender

To verify if there were significant differences between conditions regarding the Gender independent variable, an Independent T-Test was performed. Table 2 shows these results along with the descriptive statistics. There were no significant differences between Genders in either authoring tool (for $p < 0.05$). For ease of reference, the independent variables Number of Errors and Help Requests were grouped in Table 3 and the Time Spent to Complete the Protocol is presented in Table 4. The results have revealed no statistically significant difference for any of the dependent variables between male and female participants (for $p < 0.05$). Independent T-Tests were also used to analyse the independent variable Gender regarding Satisfaction, and there were no significant differences ($p > 0.05$) (Table 5).

4.7.2 Interfaces

As there were no statistically significant differences for any dependent variable regarding Gender, Male and Female participants were grouped together to study the independent variable Interface; the sample was $N = 16$ per Interface.

The Independent T-Test of Usability for the different interfaces revealed no statistically significant differences ($p > 0.05$) as is listed in Table 6.

The results for the dependent variables No. of Errors and Help Requests were grouped into one table for ease of reference (Table 7). No statistically significant differences across interfaces for both dependent variables (p > 0.05) were found.

For the time spent to complete the protocol, statistically significant differences were found between conditions; the participants that used the desktop interface were faster (6,56 ± 1153 mins) than the participants that used the immersive interface (8,19 ± 1515) to complete the given protocol, t(30) = 20,008, $p = 0.002$ (Table 8).

For Satisfaction, the results revealed a statistically significant difference between conditions; participants preferred the immersive interface (8,19 ± 1515) over the desktop interface (5094 ± 0,482), $t(30) = 20{,}008$, $p < 0.001$ (Table 9).

4.8 Results analysis and discussion

For ease of reference, the results are summarized in, where it can be easily observed that the only verified statistically significant differences between interfaces were the time spent to complete the protocol and satisfaction. Thus, the research hypothesis H1 (there are no statistically significant differences between Genders regarding Usability) and H2 (there are

Table 2 Descriptive statistics and independent T-Test regarding gender for usability

Interface	Male		Female		t	p
	M	SD	M	SD		
Desktop	86.25	10.485	80.63	9.970	t(14) = −1.557	0.142
Immersive	88.75	4.773	89.00	10.337	t(14) = −0.062	0.951

Table 3 Differences between genders on number of errors and number of help requests

Interface		Male		Female		U	p
		M	SD	M	SD		
Desktop	Errors	0.130	0.354	0.000	0.000	28.000	0.317
	Requests	0.000	0.000	0.130	0.354	28.000	0.317
Immersive	Errors	0.130	0.354	0.000	0.000	28.000	0.317
	Requests	0.130	0.354	0.000	0.000	28.000	0.317

no statistically significant differences between Genders regarding effectiveness, efficiency and satisfaction) are accepted as no statistically significant differences in any condition were verified. The research hypothesis H3 was also accepted, as there were no verified statistically significant differences across Interfaces regarding Usability. Hypothesis H4 (no statistically significant differences across Interfaces regarding effectiveness, efficiency and satisfaction) is partially rejected as statistically significant differences for the task completion time and satisfaction across interfaces were found.

Overall, Usability results show that scores of both interfaces fit into Percentile A. This means that either of the interfaces is an interface that users prefer and would recommend to others. Errors and help requests were almost nonexistent, further suggesting that the prototypes are intuitive and user-friendly. This is strengthened by the fact that Satisfaction levels reported were positive; they were, on average, higher than 5 in a scale of 1 to 7.

The independent variable Gender is known to be a factor that influences users' experience regarding task performance in VR scenarios [24, 41]. In this particular case, the present study did not corroborate such findings; it did not register any statistically significant differences between Male and Female participants for the dependent variables considered. We attribute this result to the fact that participants had a well-defined experimental protocol to complete and did not have much liberty on the task in the sense that they were not asked to be creative but rather testers. Another possible factor is personal experience with the equipment, particularly for the immersive interface, as participants were not very familiar with immersive VR equipment, namely, HMDs.

Concerning the Interfaces, there were statistically significant differences in the variables regarding the time to complete the protocol and satisfaction. Regarding the task to complete the protocol, overall the results were positive, as all participants finished the test protocol within time defined by the research team as adequate to perform the given protocol (5 to 10 min). Nevertheless, it is important to note that participants performed the experimental protocol faster with the Desktop Interface (M = 6,56 min) when compared to the Immersive Interface (M = 8.19 min). We attribute this result to the users' familiarity with 2D conventional

Table 4 Differences between genders on the time spent to complete the protocol

Interface	Male		Female		t	p
	M	SD	M	SD		
Desktop	6.25	1.389	6.88	0.835	t(14) = −1.091	0.264
Immersive	8.000	1.927	8.38	1.061	t(14) = −0.482	0.637

Table 5 Differences for gender regarding satisfaction

Interface	Male		Female		t	p
	M	SD	M	SD		
Desktop	4.875	0.518	5.313	0.347	t(14) = −1.986	0.142
Immersive	6.458	0.469	6.375	0.653	t(14) = 0.293	0.774

Desktops over an immersive VR equipment, consistent with previous studies that show that previous experience with an interface improves users' performance [5].

One interesting result is that, regardless of the fact that participants performed the tasks considerably faster in the Desktop interface, a statistically significant difference was verified in Satisfaction between the Desktop interface (M = 5.094) and the Immersive (M = 6.417), the Immersive being considerably preferred. These results are consistent with the literature that VR adds value to a variety of application areas and that immersive interfaces/equipment are preferred over conventional interfaces, bringing additional benefits in user experience and task performance [35]. From the debriefing sessions, we further theorize that such results were verified since the goal was to create an immersive VR experience; an immersive interface provides a better overview and perception of the contents that are being authored. For the remaining dependent variables, no statistically significant differences were found.

5 Discussion

The collaborative immersive authoring tool for real-time creation of multisensory VR experiences proposed here is ambitious in the sense that it raises many challenges such as not only to offer a collaborative system that allows a rapid prototype development of VR applications but also a system that is capable of supporting multisensory stimulation in a way that benefits the user experience. The experimental results have validated the feasibility of the proposal by outputting a functional prototype with two different interfaces that achieved Percentile A usability scores. This is an important step forward as it establishes an optimal platform for authoring multisensory VR experiences that overcomes the conventional methodologies that are costly at several levels. We highlight that in spite of the introduction of novel immersive interface, the usability scores from the subjective experiments (where users had negligible familiarity), were comparable to that of the highest levels shown in desktop environments. In fact, participants have rated the immersive interface slightly higher than the corresponding desktop interface and acknowledged informally with the research team the advantages of having such interface to author immersive experiences pointing that it benefits the perception

Table 6 Descriptive statistics and Independent T-Test regarding usability for the two interfaces

Desktop		Immersive		t	p
M	SD	M	SD		
83,44	10.302	88.88	7.779	t(30) = 1.685	0.102

Table 7 Mann-Whitney U tests for no. of errors and no. of help request across the different interfaces

	Desktop		Immersive		Z	p
	M	SD	M	SD		
No. of errors	0.06	0.250	0.06	0.250	128.000	1.000
Help requests	0.06	0.250	0.06	0.250	128.000	1.000

of the final scene that is being authored. The same can be explained by the fact that an immersive interface enables a more effective development of immersive experiences when compared to conventional interfaces because a desktop interface does not allow to have the 360° feeling that the final immersive experience will have. Consequently, it is harder to define and tune the multisensory stimuli without a reference of that 360 spatial dimension as it happens in the immersive interface. To the best of our knowledge, the way Content Creators typically produce multisensory content is through the code. This way of creating multisensory content does not give real-time feedback to the Content Creator and additionally requires more iteration. The literature is scarce, but the contribution for this field can have a significant impact both from theoretical and practical points of view.

5.1 Theoretical and practical implications

The knowledge gap concerning the collaborative development of multisensory virtual reality experiences has led organizations to create these virtual scenarios without any type of parallel collaboration; hence each of the actors involved in the process of creating multisensory VR experiences works in a sequential manner, drawing from the results of those who came before during the production process [3, 21]. From our perspective, this study helps to address this gap by proposing a novel authoring tool that allows to create multisensory virtual reality experiences by allowing all actors to collaborate simultaneously, hence optimizing and improving the efficiency of the editing process and, as a consequence, creating the possibility for organizations to create the experiences expeditiously. This contribution, from our modest perspective, will certainly help future researchers to draw guidelines and (functional and technical) requirements that might allow them to develop not only innovative multisensory immersive experiences but also to extend their proposals with new perspectives and assumptions.

From a theoretical perspective, the above adequacy and efficiency evaluation and its results allow us to ensure that, as argued by several authors [14], the proposed artefact may be considered a trustworthy contribution. Moreover, the description presented of

Table 8 Independent T-test regarding the time spent to complete the protocol

	Desktop		Immersive		t	p
	M	SD	M	SD		
Time spent	6.56	1.153	8.19	1.515	$t(30) = 28.008$	0.002

Table 9 Results of the independent T-test for satisfaction across the two interfaces

	Desktop		Immersive		t	p
	M	SD	M	SD		
Satisfaction	5.094	0.482	6.417	0.551	$t(30) = 29.477$	<0.001

the requirements and the specificities associated with the collaborative creation of multisensory immersive experiences might also be considered an extension to existing knowledge on the topic, particularly if one acknowledges the innovation behind the "multisensory" factor.

Aside from the arguments presented, the current research also presents a considerable contribution for organizations that are developing, or planning to develop, multisensory virtual reality experiences; the proposed authoring tool allows for not only an actual agile and collaborative approach to the development of the experiences but also real-time development, fine-tuning and testing of the content being edited. Content Creators and editors can now be fully immersed in the multisensory virtual reality experience while editing it and adjusting all necessary features, parameters and stimuli to maximize its immersiveness and sense of presence. This will allow to immediately experience the effects of changes and adjustments to the experience parameters, hence reducing the effort associated with combining all the experience elements and improving the productivity of development teams.

The fact that the proposed tool allows the rapid-development of multisensory VR applications can be beneficial for the most varied (research and business) teams, as it can be used as a tool to develop specific environments that serve as bases for studies in different fields such as phobia and post-traumatic stress disorder treatment, as an evaluation platform for assessing consumers' acceptance of new products or services; and as a platform for training and certification. In short, this authoring tool can be valuable and crucial to the multidisciplinary study and development of the relationship between virtual reality technologies and the different dimensions of human and organizational performance.

5.2 Limitations and future work

One limitation of this study is that prototypes only support the creation of multisensory 360 video experiences. Future work is planned to extend the prototypes in order to allow the immersive authoring of virtual environments and study if the results presented are the same in such condition.

6 Conclusions

There is current hype of VR, but the tools that allow the expeditious creation of VR experiences are very limited, and the development of such solutions is a costly process at many levels. With VR being a valuable technology for many applications areas, ranging from entertainment to military or medical training, there is a need to establish tools that allow the rapid development of customized solutions to take full advantage of such technology. The present work proposes a novel architecture for the collaborative and expeditious creation of multisensory VR experiences that leverages current knowledge; it supports both 360 video and VEs as bases for VR applications and supports the inclusion of haptic and smell stimuli in addition to audio and video in a fully customized manner. The use of multisensory support is justified by the fact that the more the senses engaged in a VR application, the better and more effective is the experience.

Based on the proposed architecture, we developed two different prototypes (Desktop and Immersive interfaces) as proof of concept to evaluate if such an architecture is feasible and to understand which interaction metaphor would be more suitable for such a novel approach. Even though this was a novel approach and that lack of user familiarity could have had an effect on the usability of the system and on the satisfaction regarding its use, the subjective study revealed that both of the proposed interaction metaphors were adequate. In fact, the evaluation study has revealed the pertinence of the Immersive interface, as it scored higher for both Usability and Satisfaction. Such results emphasize that when authoring immersive content, an immersive interface should be available, as it provides a better overview and perception of the contents that are being authored.

We note that the present work can become an asset for a wide spectrum of organizations in a variety of application fields, as it allows the rapid development of multisensory immersive applications that can benefit both internal and external organizational goals. Consequently, this can assist in promoting the development, adoption, and use of immersive systems.

Appendix

Experimental protocol

- Open a new project and select the videos named “Capela Nova”.
- Add a new sound stimulus and select the audio source named “Som Ambiente”. Name the new stimulus “Som Ambiente”; its start and finish times are to be 00:00 and 01:00, respectively. Then, place it in the location you want to be its origin.
- Add a new wind stimulus, and name it “Vento Ambiente”. Its start and finish times are to be 00:05 and 00:30, respectively; choose the intensity that you feel is most comfortable for this environment by testing it. Then, place it in the location you want to be its origin.
- Add a new smell stimulus, and name it “Cheiro Rosas”. Its start and finish times are to be 00:15 and 00:30, respectively; choose the “Capsule 2”, which is where the desired stimulus is; feel free to test it. Then, place it in the location you want to be its origin.
- Add a new transducer stimulus, and name it “Vibração”. Its start and finish times are to be 00:30 and 00:45, respectively; choose the intensity that you feel most comfortable with for this environment by testing it. Then, place it in the location you want to be its origin.
- Edit the smell stimulus named “Cheiro Rosas”, and change its start time to 00:25.
- Edit the transducer stimulus named “Vibração”, and change its name to “Vibração Carro” and its end Time to 00:55.
- Save the Project, and name it “Capela Nova”
- Open the Project named “England” and play it.

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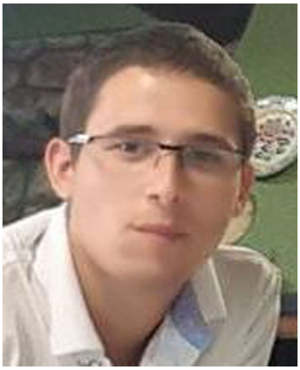

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