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DESIGNING, DEVELOPING, AND EVALUATING XR EXPERIENCES – SELECTED ASPECTS[1]

Abstract

This paper aims to highlight various aspects of the design, development, and evaluation processes of immersive XR experiences. It focuses on the creative and expressive aspects of virtual environments (VEs), following the design and implementation processes of artistic VEs as conducted by the under-

[1] The article was developed within the framework of the project "Experience and immersive technologies – from creative practice to educational theory" in partnership with Jagiellonian University, Lodz Film School, University of Malta and University of Athens (project ID number: 2020-1-PL01-KA226-HE-095891).

graduate students of the Department of Digital Arts and Cinema at the National and Kapodistrian University of Athens (NKUA) and the Department of Digital Arts at the University of Malta (UoM), in the course of three laboratory classes of Digital Artistic Creation and Immersive Experience Design, during the academic years 2020–2021 and 2022–2023. Medium-related challenges are discussed in relation to the design and implementation of user interaction, 3D content creation, 3D composition and social engagement in VEs. Furthermore, theoretical approaches of storytelling within VEs and the narrative design process of artistic VEs are discussed. Selected case studies from the students' virtual artworks are analysed in relation to the applied narrative types and structures. As a further elaboration on the evaluation of XR experiences, a CAVE system is analysed in terms of various characteristics that may affect the quality of the experience.

Keywords: extended reality (XR), virtual environments (VEs), interactive art, immersive experience design, digital storytelling, evaluation of XR experiences

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1. Introduction

Extended reality (XR) is an interaction paradigm that follows the trend of ever increasing naturalness with respect to designing human-computer interaction; this is accomplished, among others, by "spatialising" the interface in the form of virtual, augmented, or mixed reality, and by employing interaction methods that are considered more intuitive to use, such as embodied interaction, natural language, etc. This paradigm necessitates the utilisation of devices such as mobile phones, head-mounted displays, projection surfaces, and other portable or fixed infrastructure, in an attempt to increase user immersion.

Virtual environments (VEs) have emerged as a novel form of communication medium, affording the integration, composition and presentation of various types of content within a synthetic spatial context, which allow for the creation of engaging, immersive experiences. Since VEs rely on computer graphics and do not necessarily abide by the laws and restrictions which permeate physical environments, they offer opportunities for creative and artistic expression and experimentation, which remain both understudied and underutilised.

This paper aims to investigate the process of creating VEs and more specifically various aspects that pertain to the design, development, and evaluation of immersive experiences for XR. It primarily focuses on the creative and expressive aspects of virtual environments, following the design and implementation processes of the latter, as conducted by the students of Department of Digital Arts and Cinema[2] at the National and Kapodistrian University of Athens and the Department of Digital

[2] Department of Digital Arts and Cinema (NKUA), https://www.dcarts.uoa.gr/ (accessed: 20.11.2023).

Arts[3] at the University of Malta (UoM), in the course of three laboratory classes, during the academic years 2020–2021 and 2022–2023.

Since the produced VEs that are presented in the following sections are highly dependent on the available software and hardware, which affect different parameters of the experience (e.g. single-user or multi-user VEs, online or offline implementation, desktop-based or presented at head-mounted-display devices), the mutual relationship of the system and information architecture has an impact on the structure of the narrative. Therefore, the narrative design process is also discussed in detail, highlighting the medium-related challenges and theoretical approaches of storytelling within VEs.

The last section of the paper focuses on the design and evaluation aspects of CAVE, as an alternative technological platform for the creation of multi-user VEs, which presents significant differences from the respective desktop-based and HMD VEs design and development processes. These differences are highlighted through a comparative assessment of the presentation of content among the different types of VEs, as well as hybrid environments developed with augmented reality technologies.

2. Development of online multi-user VR environments and desktop-based VR environments in an educational context

In this section, a series of case-studies of the design and development of VEs in the context of educational activities in the National and Kapodistrian University of Athens and in the University of Malta are presented and discussed. Regarding the educational activities of the University of Athens, we focus on two courses on design and development of VR environments. In the case of the first course, we present observations and results drawn from students' and teaching staff's feedback. We received students' feedback through a survey conducted at the end of the course, as described at the following subsection. In the case of the second course, we present observations and results drawn only from teaching staff's feedback and the authors' direct experiences. The Department of Digital Arts at the University of Malta offers a dedicated study-unit in XR design and implementation. Additionally, this course is supplemented by related study-units that contribute, either directly or indirectly, to enriching the understanding of the subject and related skills such as 3d modelling and animation. These observations are drawn from the author's direct experiences and informal discussions with the students both during and after the course. The formal end-of-year survey, while available, has seen very limited participation.

3 Department of Digital Arts (UoM). https://www.um.edu.mt/courses/overview/UBFAH-DGAFT-2022-3-O (accessed: 20.11.2023).

2.1. Immersive Experience Design at the University of Athens

During the academic years 2020–2021 and 2022–2023 two laboratory courses focusing on the development of artistic VR environments were delivered at the Department of Digital Arts and Cinema of the National and Kapodistrian University of Athens (NKUA).

The first one was the second-year's laboratory course "Digital Artistic Creation 2", which was delivered online due to the pandemic, during the spring semester of the academic year 2020–2021. In this course the students developed multi-user online VR environments using the open source platform *OpenSimulator* (*OpenSim*).[4] The second course was the fourth-year's laboratory course "Digital Artistic Creation 5", which was delivered in-person during the fall semester of the academic year 2022–2023. In this course the students developed single-user desktop-based VR environments using the game engine Unity 3D.[5]

The objective of both courses was to teach the creation of interactive digital artworks inside 3D virtual environments. More specifically, students had to elaborate an artistic concept, design a 3D virtual environment, create 3D models and textures, design and implement a 3D composition inside the virtual environment, customise parameters of the environment (lighting conditions, terrain, and more), and design and program user interaction inside the virtual environment. The students worked in groups and the teaching staff opted for a collaborative Project-Based learning (PBL) approach.

A set of valuable observations on VR development were drawn from the students' projects developed in the context of the two aforementioned courses.

2.1.1. Observations on the development of online multi-user VR environments

In the context of the laboratory course "Digital Artistic Creation 2" 2021–2022, the teaching staff chose to work with the *OpenSim* platform. *OpenSim* is a multi-user platform for online, shared, persistent virtual worlds, based on the *Second Life* paradigm. The students were free to choose the thematic and concepts of their 3D VR artworks. The platform's setup consisted of a single *OpenSim* installation in standalone mode and the virtual world was arranged as a 5x5 extensible grid of 25 regions. Nine regions were reserved for use by instructors for carrying out virtual lectures, providing examples, and reusable assets. Eleven regions were assigned to student groups. Each student group had at their disposal an entire region equivalent to 65,536 m^2 (Anastassakis, Antonopoulou, Charitos, Katsarou, Papageorgopoulou, Sounti, 2022). The fact that no barriers were introduced between regions proved to be useful for educational purposes as students could freely navigate inside the entire world, visit the regions of their classmates, observe and potentially discuss any

[4] OpenSimulator website, http://opensimulator.org/ (accessed: 20.11.2023).
[5] Unity 3D website, https://unity3d.com/ (accessed: 20.11.2023).

creative activity by other users. They could also visit the regions reserved by the instructors, where they could find reusable assets and examples of interactive elements.

The online multi-user VR world was used for delivering lectures and communicating with the students, as well as for providing a collaborative space for the development of the students' projects. Students met online, communicated, and worked synchronously or asynchronously. They imported 3D models, developed their 3D virtual compositions, configured the parameters of the VR environment and programmed interactions, while being virtually present inside the VR world. However, technical issues, such as poor connectivity, affected the experience of creating or visiting the online multi-user VR worlds. Moreover, several students reported incompatibility issues between 3D modelling software, such as Blender, and the *OpenSim* platform. These issues were related to import and conversion of objects, the use of textures, reduction of quality, poor resolution and file size limitations, which prevented them from reaching the desired artistic outcome (Anastassakis et al., 2022).

In order to program user interaction inside the VR environments the students used *OpenSim*'s built-in scripting infrastructure which is based on the event-driven Linden Scripting Language (LSL). Some of the interactive behaviours programmed by the students included moving objects or parts, user-driven media playback, dynamic soundscapes, opening doors and barriers, guided navigation, teleporters and elevators. Students did not have to program navigation inside the 3D environments, as they used the built-in navigation and communication features provided by *OpenSim*. *OpenSim* supports first-person and third-person navigation, as well as walking, running and flying capabilities. In terms of communication, the platform provides real-time text and audio communication. Students also used the built-in *OpenSim* avatars. They customised their avatars by selecting a set of features from a menu of available options.

The fact that *OpenSim* is an open source platform, supported by a large community of users, enabled students to find shared resources on online community forums. *OpenSim*, in general terms, was proven an open source and low-cost solution, capable of supporting the laboratory course "Digital Artistic Creation 2" (Anastassakis et al., 2022).

The online multi-user VR world potentially offers an exhibition space for the VR artworks, accessible by a wider audience. Social events could also be organised inside these environments, increasing the sense of immersion and incorporation of the users into such environments (Calleja, 2011). For example, the students' presentations at the end of the semester took place inside the VR world and the students provided guided tours for instructors and classmates. The instructors used the multi-user online virtual environment as means to overcome educational limitations in the teaching of artistic laboratory courses, caused by the pandemic. They aimed at enhancing the sense of presence, to stimulate students' motivation and to encourage social interactions. A survey on the students' experience, conducted at the end of the semester revealed some advantages and drawbacks of this teaching methodology (Anastassakis et al., 2022).

2.1.2. Observations on the development of desktop-based VR environments

The laboratory course "Digital Artistic Creation 5" was delivered during the fall semester of the academic year 2022–2023 to the fourth-year students of the Department of Digital Arts and Cinema (NKUA). In this course the 3D VR artworks of the students were developed with the Unity 3D game engine. The projects' general thematic guidelines were focused on the environment and the climate crisis. However, based on these broad thematic guidelines, each group was free to develop their own concepts.

In general terms the students managed to integrate detailed 3D models and textures inside their virtual environments. Some issues concerning the integration of 3D content in Unity 3D were reported by students. Most of these issues were related to the display of imported materials and textures. Students also experimented with 3D scanning techniques using the LiDAR technology. Scanned objects were successfully embedded into the virtual compositions.

Students also paid special attention to the configuration of parameters of the virtual environment, such as the terrain, the skybox and the lighting conditions. In some projects the VR environments spanned multiple scenes. This method allowed students to apply diverse configurations of the virtual environment to each scene, resulting in a variety of aesthetic outcomes.

Additionally, students experimented with the combination of 3D and 2D elements. A group of students opted for embedding video attached to 2D planes, which appeared dynamically in specific areas of the 3D environment. Another group created a 3D composition out of multiple layers of 2D images. Most of the groups used spatialized sound and some of them used particle systems for simulating natural phenomena such as fog, fire, smoke and rain. Two-dimensional user-interfaces were embedded in the 3D worlds by some students, to provide useful information to the user.

Students programmed interactive behaviour using the object-oriented programming language C#. Some of the programmed interactions included: FPS navigation, movement and rotation of objects or parts (levers, doors), dynamic triggering of animated sequences, toggling of objects' visibility, collection of objects and storage in inventories, autonomous avatars behaviour, dynamic increase/decrease of users' energy, spatialized audio, user-driven media playback, dynamic change of lighting conditions, real-time changes of particle systems' parameters, assignment of ludic tasks (such as quizzes), conditional access to spaces, setting time limits for fulfilling tasks, dynamic transitions between scenes.

The use of the free educational version of the Unity 3D game engine was proven capable for supporting the needs of the laboratory course "Digital Artistic Creation 5". Being a widely used game engine, Unity 3D is supported by a large community of people who share educational resources and reusable assets. Some students reused free assets from the Unity asset store[6], such as FPS navigation controllers, 3D models, textures and materials. Free assets from other online databases, such Sketchfab[7] and CGTrader,[8] were also used.

Compared to the multi-user VR environments the experience of viewing single -user desktop VR artworks is a less social one. Each viewer experiences the VR environment alone and physical access to the exhibition space is required. However, the created VR artworks can be easily exported for Head Mounted Displays (HMDs), enhancing the viewer's sense of immersion.

2.2. Immersive Experience Design at the University of Malta

During the 2021–2022 academic year, the Department of Digital Arts[9] at the University of Malta (UoM) introduced a new study unit, *DGA2018 Immersive Experience Design*,[10] as a component of the Bachelor of Fine Arts (Honours) in Digital Arts programme. This novel course provides students with an introduction to mixed reality technologies and covers both technical and experiential design considerations. The immersive technologies that students are exposed to include 360 video, augmented reality (AR), virtual reality (VR), projection mapping, motion tracking, and virtual projection, aiming to provide a comprehensive and diverse experience.

As part of this course, students are taught how to generate models using photogrammetry using various tools, such as free Android-based apps, Microsoft Kinect, and software like MeshRoom for processing regular photographs. They are also instructed on how to prepare and set up models, textures, and animations in free software like Blender 3D, for use in real-time game engines like Unity 3D. The final stage of the course is focused on the actual set up of a project in Unity 3D and its deployment to a suitable device. The DGA2018 Immersive Experience Design course therefore aims to offer a comprehensive and practical approach to mixed reality technologies and provides students with a solid foundation in the technical and experiential aspects of designing immersive experiences. Overall, the course's

[6] Unity 3D asset store website, https://assetstore.unity.com/ (accessed: 20.11.2023).

[7] Sketchfab website, https://sketchfab.com/ (accessed: 20.11.2023).

[8] CGTrader website, https://www.cgtrader.com/ (accessed: 20.11.2023).

[9] Department of Digital Arts (UoM), https://www.um.edu.mt/courses/overview/UBFAHDGAFT-2022-3-O (accessed: 20.11.2023).

[10] Immersive Experience Design study unit, https://www.um.edu.mt/courses/studyunit/DGA2018 (accessed: 20.11.2023).

key focus is to introduce various concepts and demonstrate the accessibility of such technologies, particularly for learning and experimentation.

To facilitate the learning process, the course has two deliverables besides in-class workshops. The first deliverable requires each student to prepare an individual presentation about a hypothetical use of AR or VR that the student expects might be possible in the reasonable future, even using currently unavailable technology. This exercise encourages students to research existing applications of the technology and to imagine how and where this tech might find a use case that would aid or improve people's lives. The second and final exercise focuses on delivering a practical project where students get to develop an actual VR experience. The project requires students to reinterpret themselves as statues using photogrammetry techniques and create a VR environment, akin to a virtual exhibition space or museum space, in which to display their creations.

The first year of this study-unit was considered a success by the department staff. Students successfully recreated themselves as various statues using various technologies and implemented themselves in an immersive space. A particular positive aspect was how students exploited the digital space to play with scale and enhance the experience for the viewer. The course provides a foundation for students to pursue postgraduate academic development or professional endeavours in this rapidly growing sector. Several students from this cohort went on to choose an XR related area for their final dissertation project.

3. Designing storytelling in Ves

3.1. Medium-related challenges and theoretical narrative approaches

In digital storytelling, embedded stories, structured as nonlinear or multilinear narratives, are most commonly used to provide users with interactive and, up to a point, personalised experiences. From hypertext fiction and electronic literature to interactive movies and videogames, user interaction is often restricted to a choice of one among several predefined sequences of events, sustaining the creator's authorial control but limiting the user's sense of agency. The inherent features of VEs make the process of authoring and providing coherent stories with dramatically satisfying plots more complex. Freedom of movement along 6 degrees of freedom and manipulation of the point-of-view (PoV), the absence of frame and camera control, etc., may result in user behaviour within the VEs and immersive applications being relatively unpredictable. Following a plot-based, classical approach on narrative (in the sense of the Aristotelian definition or the typical three-act structure), the unrestricted movement of users may result in story discontinuities, as some narrative paths and content may be left unexplored; some parts or scenes may never be viewed or some storylines never be reached, at least within a single experience. Therefore, when dealing with pre-authored narratives, some degree of compromise between story coherence and user freedom seems unavoidable.

Predictably, story discontinuities may result in disruptions in narrative tension – in the typical three-act structure, this translates into poor development of the core story elements of suspense, curiosity and surprise. Breaks in temporality and causality, in turn, have a direct impact on temporal immersion. In the case of VR narratives that are based on game logic and present ludic elements, proper implementation of game mechanics and rules may support temporal immersion; goals and tasks provide guidance for smooth story progression, and coherence while win/lose conditions, time limitations and obstacles create the necessary suspense for building a satisfying dramatic arc. Some theorists and researchers support that interactive-ludic and narrative elements are conflicting with each other – a position largely based in the interpretation of the term "narrative" in the light of classical theory. Under the scope of post-classical theories and cognitive narratology, game mechanics may support the process of meaning-making in multiple ways. Indicatively, Mitchell distinguishes two narrative modes of game mechanics: as *experiential metaphors*, carrying their own semantics and complementing the narrative and the construction of meaning and *poetic gameplay* that encourages users to reflect on the structure of the work (Mitchell, 2023).

Louchart & Aylett (2003) use the term '*narrative paradox*' to refer to the conflict between pre-authored narrative structures and the freedom of movement that virtual environments offer. To overcome the issue, they propose the concept of *emergent narrative*, based on the user interaction with virtual agents/actors. Brand & Knight (2005) set emergent narratives in a relatively larger basis positing the environment itself as a carrier of potential narratives. Except for interacting with characters and virtual agents, emergent narrative also "occurs when the player imagines or 'authors' the story by playing in a world she actively constructs". While active construction, closely interpreted, suggests the ability to dynamically configure / alter the content of the environment (in the style of sandbox games), on a smaller scale, any user interaction with the environment that results in modifications of its elements[11] may carry semantic weight and potentially create narrative content.

As Ryan (2018) observes, VR narratives score lower on temporal immersion compared to other mimetic media, and higher in spatial and emotional.[12] Focus-

[11] As Brand & Knight (2005) put it, "player interaction with the environment leaves a mark in the mise-en-scene".

[12] Broadly speaking, immersion can be conceived in two ways: as a technological effect and as a mental state (Ryan, 2018; Ermi, Mäyrä, 2005; Mäyrä, 2008; Adams, Sweeney, 2009; Jerald, 2015). These two are interconnected, as the immersive qualities inherent in each medium may induce variable mental effects to the users. Ryan (2018) in particular notes that immersion in VR, as a technological effect, results from both the interactivity and the visual features (3D representation & 360 image of the virtual world). As a mental state she discerns the categories of ludic immersion (related to gameplay) and narrative/mimetic immersion experienced in a variety of forms: spatial immersion (configuration of space, navigation within the environment and the sense of place), temporal immersion (narrative

ing on spatial immersion, she disconnects narrative from the established plot-based sense of the term by proposing an expanded theoretical framework based on spatial properties and placing the environment itself at the centre of interest. Jenkins (2004) also focuses on the spatiality of narratives for the creation of immersive narrative experiences and characterises (game) designers as narrative architects, stating that "choices about the design and organization of game spaces have narratological consequences". He further discerns four different but often co-existent modes: *evocative* as pre-existing narrative associations, *enacted* as the setting for narrative events, *embedded* as story-related information within the mise-en-scene and *emergent* as spaces providing resources for dynamic creation of stories (Jenkins, 2004). In the same direction Ensslin (2015) notes that player choices and interaction with the environment and its contents have the potential to evoke narrative scripts.

3.2. Investigating the design process of narrative experiences for desktop-based VR environments.

In this subsection, three selected student projects delivered for the laboratory course "Digital Artistic Creation 5" (academic year 2022–2023) are presented and discussed in brief in relation to the applied narrative types and structures. The specific artworks were chosen as a sample based on the diversity of the used storytelling techniques. Also, the common topic and general thematic guidelines, which the students had to follow for the development of their projects, as described in the above section, serve for discussion focused on structural narrative characteristics rather than conceptual content analysis. Projects developed for the laboratory course "Digital Artistic Creation 2" (academic year 2020–2021) were excluded from the current analysis due to the technical issues that prevented students from reaching the desired outcome, as reported above in the corresponding section of the paper (see "Observations on the development of online multi-user VR environments'").

For the design of the narrative content of the artworks, the students followed a series of steps as described below:

- general concept definition;
- definition of setting, time frame, characters and/or environmental features, and interactive elements;
- outline of the plot (if any) and detailed scenario;
- interaction design and navigation with respect to narrative content;

tension as derived from experiencing of the core narrative elements of suspense, curiosity and surprise and, in interactive environments based on game mechanics, from performing certain actions within limited time) and emotional immersion (in the form of empathy and, in computer games, from the sense of achieving or failing to complete a goal).

- segmentation of story into parts, rearrangement of the segments for the creation of narrative paths (formation of linear, multi- or non-linear structures) & graphic representation of plot graphs (story maps);
- storyboards (as rough sketches including a general map of the space with indications for user navigation, accompanied with notes for spatial affordances for interaction, the placement of interactive objects and sound design);
- moodboards (describing the textures, colour palette, ambiance, overall style and aesthetics).

The VE created by the first group of students (M. Bitos, A. Roussi, G. Tsiantaris, E. Charmantzi) comprises three distinct areas/parts, the introductory one functioning as a menu and point of reference and two alternate worlds. The user is positioned inside a dark empty space on the vertical surfaces of which still depictions of the other two areas lie obscured. The interaction within the dark space is limited in controlling a square-shaped light – activated only at the vertical boundaries of the space – for the exploration of the area, the discovering and activation of the entry points which teleport him to the region of his choice. Once entering one of the alternate worlds he is able to navigate freely through the environment (in opposition to the confined movement in the dark space) and interact with the elements placed within it. At any time, the user can go back to the introductory area by returning to the teleporting point (Fig. 1).

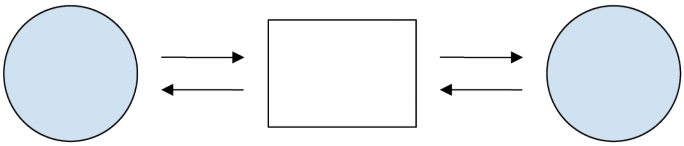

Fig. 1. Narrative structure of Project 1 (M. Bitos, A. Roussi, G. Tsiantaris, E. Charmantzi, Digital Artistic Creation 5 laboratory course, Department of Digital Arts and Cinema, NKUA, 2022–2023). White rectangle: entry point/menu, blue circles: navigable interactive alternate worlds (non-linear).

In overall, the artwork presents an open, segmented, modular narrative structure; the three parts are not connected from a spatiotemporal point of view, but are related conceptually and aesthetically. Spatial storytelling techniques in the form of evocative narratives are applied through the audiovisual design of the environment and the interaction affordances. Interactive objects in colours and textures rich in symbolic meaning evoke conceptual connotations. In addition to visual elements that act as landmarks, subtle guidance is provided through ambient sound design.

When examined individually, the two storyworlds do not present fixed embedded narratives or predefined paths. Instead, the story emerges from the player's navigation through the environment and interaction with the embedded elements.

The user's actions have a direct impact on the VE, modifying its visual appearance. For instance, trees made of cardboard are burning when the user gets close to them – a direct metaphor for the destructive human intervention in the physical environment.

The artwork created by the second group of students (S. Bairas, S. Panousis, C. Fotinas-Voinas), employs game mechanics to provide guidance and sustain story coherence. While the user can navigate freely in the VE, tasks have to be completed in a certain order and clues must be gathered to advance the story. The presence of gameplay aspects in the style of adventure games (exploration, interaction with objects and collectibles, clues, tasks and goals) favours ludic over mimetic immersion.

Based on gameplay and mechanics, attention was given to the interactive objects placed in the environment and collectibles that served multiple purposes: (i) as restrictions and motivations, a certain listed number of objects (collectibles) had to be collected encouraging the user to explore the whole environment, (ii) as guidance and as means to sustain narrative coherence, objects that had to be used to complete tasks in a logical order, (iii) as story promoting elements, items and elements (i.e. lists, notes, a TV-set) carrying narrative meaning or as embedded micro-narratives.

Overall, the artwork presents a linear narrative structure in the form of a "string of pearls" variation (Fig. 2) or a level-like organisation with three discernible narrative parts (beginning, middle, end). Users have to perform certain actions to advance to the next parts of the story with no option to return to the previous ones. In each of these parts, the user is transported in the exact same location of the environment but in a different time-frame or alternate reality. While the spatial arrangement of the VE remains unchanged in each of the "alternate realities", the *mise en scène*, colours, light and the atmosphere appear changed, as well as the offered interaction affordances, placing the user in a different narrative context. This technique creates temporal loops giving the sense of non-linearity on the level of narrative discourse.

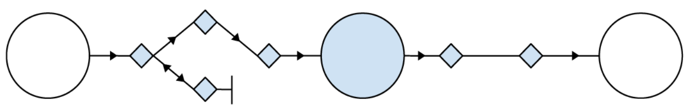

Fig. 2. Narrative structure of Project 2 (S. Bairas, S. Panousis, C. Fotinas-Voinas, Digital Artistic Creation 5 laboratory course, Department of Digital Arts and Cinema, NKUA, 2022–2023). White circles: starting – ending points, blue circles: significant narrative events, blue rhombi: nodal point – points requiring user interaction.

The third student group (A.K. Gleka, K. Kourmpoglou, F. Marampidou, A. Filidou) experimented on the implementation of cinematic elements (2D non-interactive video sequences with narrative content in style of video game cut-scenes) within an interactive 3D VE. As with the student group that developed the first project, the creators of this project deliberately decided not to employ typical aspects of gameplay, such as quests, goals or win/lose conditions, and to focus on mimetic rather than ludic immersion, relying mostly on exploration mechanics and limited interaction with embedded elements.

The project follows a semi-structured storyline and subtle guidance is offered through the spatial design of the environment in form of affordances, restrictions and landmarks. Users may follow the designed predetermined path or navigate and explore the environment at their own will. Visual cues, such as a paved road and obstacles are used to direct the user towards narrative significant areas and routes on the VE. The artwork combines evocative – environmental type of storytelling with embedded micro-narratives in cinematic form. With focus given on discovery, the story is primarily perceived through exploration and interaction with the VE and complemented by the cinematic elements used to intensify narrative tension.

In general, it presents a relatively loose, nonlinear branching structure with "semantic" foldback (Fig. 3). A dominant element, an entrapped whale, visible from distance and from various locations within the VE guides the user toward the ending point where he faces a moral dilemma and has to make a (seemingly) decisive choice: either he chooses to save the creature which, with its energy feeds the world and, consequently, bring the world to its end or he continues to wander in a near-destructed environment. However, the user's decision doesn't actually affect the final outcome – the status and the fate of the world cannot change whether he chooses to take action or not. Thus, the user either experiences an open-ended (by not taking action) or a closed-structure narrative.

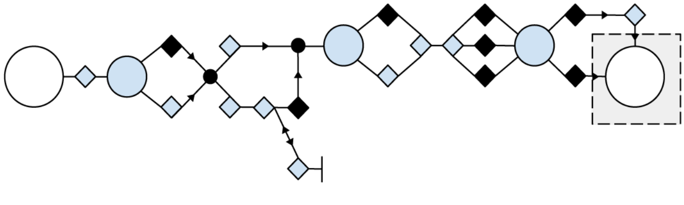

Fig. 3. Narrative structure of Project 3 (A.K. Gleka, K. Kourmpoglou, F. Marampidou, A. Filidou, Digital Artistic Creation 5 laboratory course, Department of Digital Arts and Cinema, NKUA, 2022–2023). White circles: starting – ending points, blue circles: nodal points – narrative prompting events, black circles: connection points, blue rhombi: points requiring user interaction, black rhombi: non-interactive video projections.

3.3. General Observations

Given that the selected sample was relatively small to conduct an empirical study and proper quantitative analysis, no solid conclusions could be extracted. Instead, some initial observations are listed above.

- Regarding the design process, the student groups in general followed a holistic approach of designing narrative along with the audiovisual elements of the VEs, mechanics, navigation and interaction affordances. The attention given to narrative gives additional meaning to spatial structures. As Nitsche (2008, p. 45) remarks, narrative elements can generate context and significance to make the space and its experience more meaningful. Furthermore, the provision of narrative elements in addition to the sensory aspects of the environments may facilitate user immersion, since immersion is not only a byproduct of technological factors, but contains non-sensory aspects as well (Therrien, 2014). The discussion on immersion and its components is vast – some indicative examples include the following: in the context of game studies, Ermi and Mäyrä (Ermi, Mäyrä, 2005; Mäyrä 2008) refer to imaginative immersion, while Calleja (2011) discusses the concept of narrative involvement as part of the Player Involvement Model. In his discussion of design practices for Virtual Reality, Jerald (2015, p. 45) lists plot (i.e. portraying and conveying an experience, a sequence of events, and the behaviour of the world and the entities it contains) as a component of immersion.
- In all cases more emphasis was given to environmental storytelling – the narrative derives from the audiovisual and spatial design of the VEs with support of mechanics. None of the produced narratives was character-based: absence of narrators, secondary characters or antagonists, no interaction with agents, the human presence is only implied.
- While all projects were based on environmental storytelling, they present great diversity in the applied techniques, narrative modes and structures.
- The varying degrees of guidance seem to affect the coherence of the narrative and the building of dramatic tension (from more to less coherent: project 2 > project 3 > project 1).

4. Evaluation of XR technologies

In contemporary practice, UX evaluation has moved away from a purely or largely functional perspective towards encompassing a multitude of subjective factors that may influence the overall perception and, ultimately, the experience of an interactive system. In the case of XR, a rise in the importance of hitherto overlooked aspects, namely those related to ergonomics and human factors, is evident. An XR system comprises various physical objects that may span the entire spectrum of the interaction, from input/output devices (e.g. head-mounted displays, projection surfaces, control devices such as joysticks and wands) to the infrastructure (such as seats, locomotion devices such as corridors) and the arrangement of the interaction space itself (e.g. dimensions, shape and spatial configuration). Any meaningful attempt to evaluate UX in the context of XR systems cannot afford to completely overlook any of these aspects, as each and every one of them may affect the overall quality of the experience.

The multitude of salient factors that contribute to the overall quality of the User Experience preclude a singular approach, since the relative importance of each factor is determined by the characteristics of the XR system in question – e.g. what input/output devices are utilised, how many (and which) sensory modalities are involved, what the intended duration of the interaction is, what is the main user category the XR experience is designed for, etc. In any case, the importance of ergonomics is accentuated with the rise of XR technologies, as these rely to a significant extent on wearable devices and/or the utilisation of physical space. With that in mind, in the subsections that follow, a representative case of XR interaction, namely the CAVE system, is described from the point of view of UX evaluation. Projection-based setups are a commonly chosen solution when the goal is to involve several users simultaneously without the need for individual equipment such as HMDs, and the CAVE is one of the most widely used implementations of projection-based XR.

4.1. Designing for a C.A.V.E. system

Originally developed in the early 1990s (Cruz-Neira et al., 1992), a C.A.V.E. (Cave Automated Virtual Environment) is a fully, or semi-enclosed space, composed of various displays, designed to immerse a viewer in a space, without the use of HMDs (Head Mounted Displays). The University of Malta houses such a system as part of MAKS Immersion laboratory, called the SIntegraM Cave. 'SIntegraM – Developing Spatial Data Integration for the Maltese Islands (Formosa, 2019) is an EU funded project as part of *Operational Programme I – European Structural and Investment Funds 2014–2020* and the SIntegraM Cave is one of the technologies employed to visualise the outputs of the projects amongst other uses.

Such a space offers various advantages since it is a space akin to a small cinema, and therefore feels relatively familiar to visitors new to virtual or mixed reality experiences. C.A.V.E. setups also facilitate communication, group exploration and collaborative work amongst viewers, since these are physically present within the same space and visible to each other. Visitors to the lab are generally less hesitant to try out a C.A.V.E. experience compared to an HMD when they are wary of technology.

4.2. Managing Contrast Issues in the C.A.V.E.

One of the issues with projector-based systems is a possible lack of contrast in the projections. This problem arises due to the presence of multiple projectors emitting light within an enclosed space. Even a single projector will display grey in pitch black areas. Multiple projections within the same space wash out the projections due to all the bounced light.

The majority of projects displayed in the SIntegraM Cave are static meshes of real environments generated through photogrammetry or Lidar scans. Three key design considerations have helped improve the contrast issues in certain circumstances.

1) Leaving a black background and avoiding the use of skies and other atmospheric effects unless necessary to the project in question.
2) Using a relatively dark virtual pointer to represent the controller. A shade of purple worked well, as it still provided suitable contrast with the photogrammetry generated backdrops in our dataset without adding too much projected light to the experience.
3) A "Shadow Caster", or a black disk shaped object parented to the back of the lead viewer camera. This ensured that the back of the main viewers point of view was not contributing unnecessary light to the experience.

While the result is still not ideal as noticeable by the improved contrast and colour reproduction in naturally darker datasets, the above methods helped alleviate some of the issues.

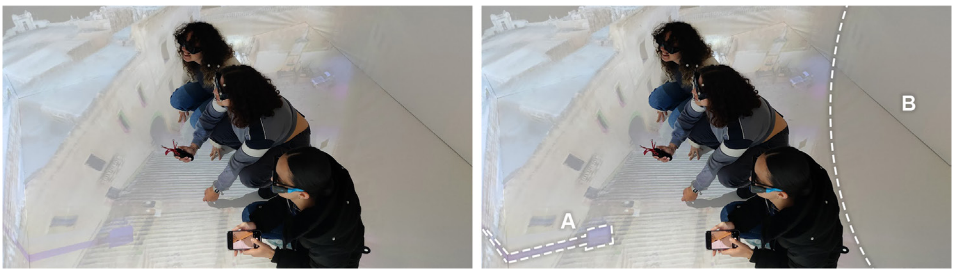

Fig. 4. Images showing lack of black and contrast in projection space as well as partial solutions with pointer (A) and shadow caster (B). Source: Calì (2023).

4.3. Head Mounted Displays: design aspects

On a practical note, HMDs are easier to obtain and operate by individual users and are suitable for a variety of content types – e.g. 3D movies, interactive content. The use of Head-Mounted Displays [HMDs] caters to each user independently, thus eliminating contrast issues encountered in CAVE systems; furthermore, users have control over their movement in the VE, thus negating the need for centralised control of the interaction, an issue that is commonly encountered in projection-based multi-user systems. Additionally, the issue of off-centre distortion (whereupon participants who are located away from the centre of the projection space perceive visual elements as distorted) does not apply in HMD-based experiences.

On the other hand, HMDs may present ergonomics-related challenges; factors such as weight, form factor, comfort, interpupillary distance, and even temperature may negatively affect the experience during prolonged use. Furthermore, motion sickness and its associated adverse effects are more likely to occur when using HMDs. Aspects such as field-of-view and refresh rate (and, specifically, avoidance of lagging or 'frame drops') are crucial in ensuring that the overall experience will not degrade due to adverse effects, which, in extreme cases, may result in the users terminating use of the system.

4.4. Comparative assessment of XR content across different platforms at the MAKS Immersion Laboratory-Malta

The MAKS Immersion Lab at the University of Malta houses various immersive technologies. However, the three that have been in use the longest are the SIntegraM CAVE, the Magic Leap CE1, Oculus Rift and the Oculus Quest 1. These devices exhibit significant differences in their design and intended applications. Nevertheless, their application to review common datasets presents an opportunity for comparative research.

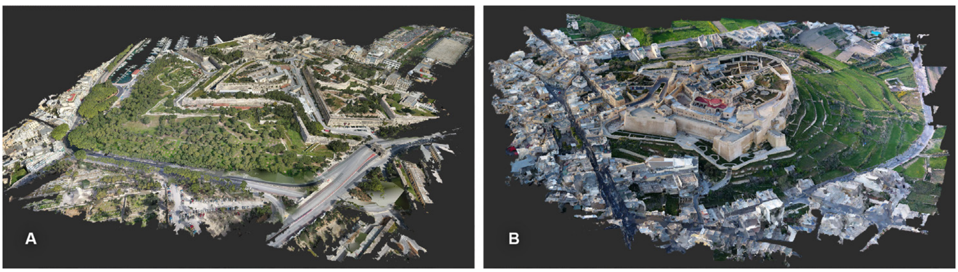

Fig. 5. SIntegraM sample datasets used in the lab. A: Floriana – 10 m triangles. B: Citadella – 3.6 m triangles. Source: Formosa (2019).

A brief summary of the technological setup is found in Table 1. A summary of the observations is available in Table 2.

Table 1. Brief Technology summary

	C.A.V.E.	Magic Leap	Oculus Rift	Oculus Quest
Brief Technology summary	3 m × 3 m Cube room 7 Optoma DLP projectors 6 Optitrack IR cameras 3 Volfoni Edge RF 3D Glasses Playstation Move Navigation Controller Controller & Glasses with IR reflectors 8 Nvidia Quadro based PCs	Version CE1	Version 1 External sensors Tethered to various PC setups	Version 1

Contrast & Blackness

One of the significant distinctions among virtual reality (VR) devices concerns their handling of dark environments. The C.A.V.E. system, which is projector-based, is challenged by brighter scenes that can dilute the contrast. Additionally, dark areas can be easily subdued as a result of the light bouncing around in the confined space. On the other hand, the Magic Leap, like the Oculus headsets, can display very vibrant images. However, it is less effective than the Oculus devices at handling darker scenes due to its overlay of virtual displays onto the real world, which renders the brighter aspects of the virtual and real worlds visible.

Portability

The C.A.V.E. system comprises an aluminium frame with stretched screens, 7 projectors, 6 IR cameras and 8 computers. Although originally intended to be portable, it is generally challenging to dismantle and reassemble with ease, especially when compared to the convenience of a wireless head-mounted display (HMD), such as the Magic Leap or Oculus Quest. For temporary C.A.V.E. experiences held in different venues, renting equipment for projection mapping may be more suitable for most of our intended purposes and datasets. While the Oculus Rift 1 can be moved around with relative ease, it requires a longer set-up time due to the need for wired connections to a computer and the calibration of external sensors.

1:1 scale experience

One of the most intriguing features of virtual reality (VR) experiences is the capacity to adjust the scale of visual data. The captured scenes can be viewed at their original size or scaled up or down as needed. Except for the Magic Leap, all the equipment performs well, regardless of whether the data is viewed at a 1:1 scale or scaled up or down. The Magic Leap's display is smaller than the viewable area, resulting in a sharp display discontinuity where the display section ends. This is not as noticeable when viewing individual objects, but it is evident when experiencing scenes that envelop the user.

Locomotion

Flying or teleportation is the preferred method of moving around in VR on most devices in our setup. This is due to the fact that a lot of our captured data has very irregular terrain. This floor variance in the experience can increase the likelihood of motion sickness.

However, there is an exception with the Magic Leap, where the visual data is frequently locked in space, and the viewer walks around the physical space to view the scenes. This is because both the virtual and the real world are simultaneously visible, and flying through the virtual world while the real world remains static can be an uncomfortable experience for users.

Moving in the Real World

The C.A.V.E. and Rift exhibit physical limitations with respect to the enclosure space and tether distance, respectively. Empirical observations suggest that individuals using the Rift are prone to minimising their physical movement in the real world to avoid interference with the attached cable. Conversely, users of the wireless Quest system tend to move more freely. Furthermore, the Magic Leap users demonstrate a greater degree of mobility, attributed to their ability to visualise both the virtual and real-world surroundings simultaneously.

Ease of Data Deployment

The C.A.V.E. and Rift rely heavily on the capabilities of the computer driving them, whereas the Quest and Magic Leap have their own processing units. The Magic Leap C1 has proven to be capable of handling all datasets used on desktop-powered devices. On the other hand, the Quest 1 required substantial optimization in order to use the same Photogrammetry-generated models.

Setup & Calibration

The setup and calibration process varies among the devices. The Quest is a straightforward process, simply marking the safety area and loading the project. The Rift 1, on the other hand, requires the setup of sensors and calibration. The Magic Leap is generally a positive experience, although some setup is required while scanning the environment for meshing. This process can also introduce temporary artefacts in case of objects moving in the real environment.

The C.A.V.E is the more complex device. Since our setup runs off eight networked computers, there are occasional syncing issues to be ironed out whenever the system needs to be restarted.

Maintenance

The Quest and Rift are characterised by their simplicity and ease of use, with automated updates and minimal maintenance requirements. An exception being that the Rift's sensors necessitate recalibration in the event of any alteration in their position. Similarly, the Magic Leap demands regular updates in addition to annual renewal of Development Certificates. While some of these Magic Leap updates install automatically, others require manual installation via computer command line. As for the C.A.V.E, regular recalibration is essential to account for minor structural shifts that cause projection misalignment at the edges of the screens over time.

The following table summarises the comparison of the devices mentioned above in terms of the various dimensions that have been the focus of this section. The evaluation presented here is a result of informal observations conducted by research officers tasked with project deployment and management at the MAKS Immersion Lab, including the author. A recurrent necessity across our projects requires relatively uniform data deployment across diverse devices, enabling comparative assessments of user experiences on a device-to-device basis. Moreover, unstructured feedback gathered from diverse laboratory guests interacting with the same data sets on various devices supplements this evaluation, offering insights into user experiences. These initial insights serve as a preliminary exploration, potentially informing a more structured and comprehensive comparative study in subsequent research endeavours.

Table 2. Comparative overview of different devices

	C.A.V.E.	**Magic Leap**	**Oculus Rift**	**Oculus Quest**
Contrast	Weak	Variable	Good	Good
Blackness	Weak	Not available due to passthrough screen	Good	Good
Portability	Difficult	Excellent	Variable	Excellent
1:1 scale experience	Excellent	Weak for large scenes	Excellent	Excellent
Locomotion (Fly-mode)	Comfortable	Awkward	Comfortable	Comfortable

Moving in Real world	Comfortable but preferable to remain close to centre	Excellent	Limited (due to tether)	Comfortable
Ease of Data Deployment	Good. Can handle photogrammetry datasets comfortably without major optimization. Limited to PC desktop power	Good. Can handle photogrammetry datasets comfortably without major optimization. Limited to PC desktop power	Good. Can handle heavy photogrammetry datasets comfortably. Limited to PC desktop power	Weak 3D Models need considerable optimization
Setup & Calibration	Poor due to syncing issues in 8 computer setup.	Reasonable Real Space recognition is the major delay.	Reasonable	Easy
Maintenance	Poor due to projector shift.	Variable but reasonable.	Easy	Easy

This table, summarising the casual observations and informal feedback gathered in the Immersion Lab, illustrates that interaction design for XR experiences can vary significantly depending on the technology to be used and desired user experience.

5. Concluding remarks and future directions

Experience design for XR applications is inherently multidimensional, with a multitude of factors, both objective and subjective, affecting the overall quality of the experience. This variety, in turn, increases the complexity of designing, developing, and evaluating XR systems and content; it is important to approach the process of design, development, and evaluation in a holistic manner, so as not to overlook potentially important issues that may ensue across the entire spectrum of the interaction with XR technologies and that may negatively impact the overall experiential quality of the interaction.

In the preceding sections, indicative XR use case scenarios from higher education institutions in Greece and Malta have been analysed in terms of experience design, development, and evaluation, approaching the issue from the point of view of storytelling and narrative. Finally, with evaluation in mind, a representative case of projection-based immersive systems, namely the CAVE, is examined as a means to identify important aspects that affect user interaction in a complex system that utilises several interaction devices.

Notwithstanding the importance of hardware and infrastructure in general, potential future directions in XR research should also encompass the need for properly structured and adequately grounded content that effectively leverages the particular characteristics of the medium for the purpose of achieving a high degree of immersion and user engagement. To that end, a multidisciplinary approach that incorporates elements from various fields (depending on the domain) is advocated – in this paper, storytelling and narrative are showcased, but the spectrum of Interaction Design is quite wide and incorporates contributions from other fields and disciplines from the sciences, arts, and humanities, all of which become increasingly more important in light of XR applications.

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