Design methodology for 360-degree immersive video applications

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A thesis submitted to the University of Westminster in partial fulfilment of the requirements for the degree of Doctor of Philosophy

January 2020

Dedication

To my father, George C. Argyriou, mathematician
-for teaching me the value of problem solving and for always supporting me-

Στον πατέρα μου, Γεώργιο Χ. Αργυρίου, μαθηματικό
-που με δίδαξε την αξία της επίλυσης προβλημάτων και που πάντα με στηρίζει-

Declaration

I declare that all the material contained in this thesis is my own work. The work in this thesis is based on research carried out at the University of Westminster, College of Design, Creative and Digital Industries, School of Computer Science and Engineering. No part of this thesis has been submitted elsewhere for any other degree or qualification.

Signed: (Lemonia Argyriou)

Date: 31/1/2020

Abstract

360-degree immersive video applications for Head Mounted Display (HMD) devices offer great potential in providing engaging forms of experiential media solutions. Design challenges emerge though by this new kind of immersive media due to the 2D form of resources used for their construction, the lack of depth, the limited interaction, and the need to address the sense of presence. In addition, the use of Virtual Reality (VR) is related to cybersickness effects imposing further implications in moderate motion design tasks.

This research project provides a systematic methodological approach in addressing those challenges and implications in 360-degree immersive video applications design. By studying and analysing methods and techniques efficiently used in the area of VR and Games design, a rigorous methodological design process is proposed. This process is introduced by the specification of the iVID (Immersive Video Interaction Design) framework.

The efficiency of the iVID framework and the design methods and techniques it proposes is evaluated through two phases of user studies. Two different 360-degree immersive video prototypes have been created to serve the studies purposes. The analysis of the purposes of the studies ed to the definition of a set of design guidelines to be followed along with the iVID framework for designing 360-degree video-based experiences that are engaging and immersive.

Acknowledgments

First, and most of all, I would like to thank my PhD studies supervisor, *Dr Daphne Economou*, for her unlimited support throughout this research project’s lifecycle, her patience and valuable guidance. Special thanks also to my second academic supervisor, *Dr Vassiliki Bouki*, for the important recommendations on conducting this research. Both made a valuable impact on my professional learning and development, and for that I am incredibly grateful.

Special thanks to the *University of Westminster* which supported my work financially and provided me with all the means necessary for conducting my research, study and writing up my thesis. I would like to also thank the XR-Lab team for offering the facilities and technical support for conducting the user studies and the *Serious Games at Westminster* (SG@W) for discussing further research directions. Many thanks also to the staff members and the students of the *University of Westminster* that took part in the studies.

This research project would not be possible without the contribution of *Nikos Papadopoulos* who I would like to immensely thank for assisting with the creation of the prototype applications and *Aris Kidonakis* and *Dr. Angelos Hliaoutakis* for their valuable insights and help. Special thanks to *Dr. Melda Küçükdemirci* and *Dr. Maria Cristina Manzetti* for their help in 360-degree video production by supporting the role of human actors.

Many thanks also to *Dr. Ioannis Doumanis* and *Stuart S. Porter*, former CTVC employees, for providing directions in defining the user requirements in the area of 360-degree immersive video.

Finally, I would like to thank *my family, my partner Ioannis and my friends* for their tolerance, love and limitless support.

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Abbreviations

AR	Augmented Reality
CH	Cultural Heritage
COTS	Commercial Off The Shelf
Dr	Design requirement
FoV	Field of View
GUI	Graphical User Interface
HCI	Human Computer Interaction
HMD	Head Mounted Display
iODV	Interactive Omnidirectional Video
IVE	Immersive Virtual Environment
iVID	Immersive Video Interaction Design
IxD	Interaction Design
MR	Mixed Reality
POI	Point of Interest
UI	User Interface
Ur	User requirement
UX	User Experience
SDK	Software Development Kit
SoA	State of the Art
VPL	Visual Programming Lab
VE	Virtual Environment
VR	Virtual Reality
XR	Extended Reality

Chapter 1

1 Introduction

The desire for better immersion and presence in computer simulated environments has driven an aggressive growth of immersive technologies, presenting new forms of Virtual Reality (VR) media and innovative VR devices. A promising technology for immersive experiences design is the 360-degree video that can provide spatial immersion through Head Mounted Displays (HMD) (Elmezeny et al., 2018). 360-degree video offers enhanced realism that although it would be possible to be produced using computer generated virtual environments, it is resource intensive and expensive process (Bleumers et. al., 2012). This enhanced realism, offered by the 360-degree video resources used (Chambel & Guimarães, 2002), when combined with advanced interaction techniques has great potentials of leading to highly immersive and engaging forms of new media. 360-degree video applications are based on free viewpoint videos and resemble navigation in virtual worlds of 3D computer graphics by allowing viewers to interactively change their viewpoint in the scene (Smolic et al., 2006) while in traditional video production the viewpoint is chosen by the director. At the moment, the interaction mainly supported in such applications is limited to:

- the change of viewpoint by the users enabling them to look around in the 360-degree captured video scene;
- the selection of hyperlinks integrated in the video in different times and areas to either:
  - load another 360-degree video replacing the current scene giving the feeling of transitioning to another virtual environment, or;
  - load multimedia content that can either replace the current scene, or be overplayed in it (Neng & Chambel, 2010).

In contrast to computer generated VR environments, in applications built using 360-degree video the challenge of navigating in the environment and interacting with the content must be addressed, imposed by the lack of the sense of depth in the virtual scenes. The areas of VR and Games Design provide insights in addressing interaction and experience design issues, but there are not specific design approaches that could be applied in 360-degree immersive video.

The work of Adão et al. (2018) introduces a preliminary system specification for prototyping immersive experiences based on 360-degree video complemented with other forms of multimedia content reporting on good levels of functionality-centred usability. Further to this work, concrete methods focusing on intuitive interaction design for VR device 360-degree video immersive experiences should be identified, applied, and extensively evaluated following a more rigorous approach.

Though current technology is mature enough to support immersive experiences, the lack of a systematic design approach for this new kind of 360-degree video-based solutions suggests further research work on this area. This study focuses on the definition of a methodological framework for guided design that could be followed in 360-degree video applications targeting the production of immersive and engaging experiences. To serve this purpose the research methodology includes user studies aiming to define and evaluate a list of different applicable design methods and approaches defined by following the framework introduced.

The final study outcomes propose a list of design guidelines for the creation of engaging 360-degree immersive applications.

The following sections provide a description of the research objectives, the challenges identified, and the methodology followed to achieve those and the key contributions concluding with the analysis of this thesis structure.

1.1 Research Objectives

The proposed research project aims to contribute with original knowledge to the fields of: Human Computer Interaction (HCI); Virtual Reality (VR); Immersive video and Games Design through its results. The introduction of 360-degree video applications in the area of VR as a new form of immersive experiences supported by the use of VR headset devices imposes challenges for further investigation on how interactive and engaging experiences for those means can be effectively designed.

360-degree video applications that have been released the past years offer low levels of user interaction with the content failing to engage the user at the same level as in VR applications and Games. Therefore, by studying the main design techniques that are used in the area of VR and Games design, which offer highly engaging experiences, this PhD research is expected to generate important outcomes on designing new forms of interactive and immersive media experiences.

To achieve this aim, a list of related objectives should be addressed:

> **OBJ1:** The first objective is to study this new technology thoroughly in order to identify the challenges imposed when using 360-degree video to create interactive and immersive experiences for VR headsets.
>
> **OBJ2:** The second objective is to provide a rigorous methodology for the analysis of the design aspects in the area of 360-degree immersive video solutions and the corresponding techniques that could be followed. This methodology intends to address the challenges identified.
>
> **OBJ3:** Depending on the application purposes and the technical means available, a set of design techniques and methods should be specified to guide the designers of 360-degree immersive video experiences. A third objective therefore is to thoroughly analyse the procedure for developing working 360-degree immersive video prototypes following the methodological steps proposed and the incorporation of the design techniques identified.

OBJ4: The final and most important objective is the introduction of a set of design guidelines for the area of 360-degree immersive video solutions aiming to guide the interested developer communities in providing new forms of interactive and engaging experiences. This requires a research methodology designed to focus on user experience research and real user studies.

1.2 Challenges in 360-degree immersive video design

While there are several recent research projects proposing methods for addressing specific interaction design tasks for 360-degree immersive video, such as for the viewing direction (Li et al., 2018, Hu et al., 2017, Rothe & Hußmann, 2018), there are no significant results, or thorough studies providing a holistic methodological design approach for this new kind of immersive experience. The use of video as the main element for the virtual environment creation of such applications makes current approaches and guidelines related to the design of common 3D VR and games applications not adaptive as such. Therefore, all these methods and techniques should be re-examined and re-specified to allow their applicability in the context of 360-degree immersive video design. Creating a virtual experience based on video resources and not computer-generated graphics introduces a set of new challenges that need to be addressed. At the first stage of this PhD research a list of challenges has been identified that designers of 360-degree immersive applications need to address in order to offer interactive and engaging experiences. A more complete specification of the challenges that need to be addressed in 360-degree application design is provided in Section 4.2.

Those challenges are divided to two categories:

A) **Technical challenges** that deal with implementation and development issues when creating such applications

Ch1: Smooth transition between video resources

Ch2: Natural, close to real environment

Ch3: Reality-based navigation

B) **Design challenges** that focus on the overall design issues when creating such experiences.

Ch4: Non-intrusive, non-distractive user interface design

Ch5: Navigation and orientation mechanisms

Ch6: Gamified design

Users of successful VR applications should feel immersed and engaged throughout the overall experience. Therefore, there are challenges in the design of such applications in order to avoid breaking those feelings. In contrast to common VR application design, in 360-degree immersive video new methods need to be investigated for designing interaction with the virtual environment due to the lack of depth and space of the video display scenery. In order to integrate a video resource in a 3D application the video scene itself should be mapped and projected on a 3D object, such as a sphere or a pyramid (Facebook Engineering post, 2016). The boundaries and geometry of the 3D scenes are therefore restricted. The whole experience, the interaction, and the user interface (UI) should be designed following the video display. Moreover, experiences for a new form of VR devices should complicate the process, due to the effects of nausea and cyber-sickness related to their user (Stanney et al., 1997).

Design methods derived from the area of VR and Games could address those challenges but should be re-examined and adapted to serve the needs of 360-degree immersive video experiences. Such design methods deal with aspects of narrative design, virtual scenes' design, the role of virtual actors in those environments, UI design, navigation design and gamified design. Gamified design techniques based on the concept of gamification and serious games (see Section 2.8) are being further explored and experimented for the case of 360-degree immersive video. Those techniques are promising for engaging further the viewer while educating them through a new form of immersive and interactive storytelling experiences.

The requirement for more engaging and interactive forms of 360-degree immersive video experiences was driven by literature review on this topic and discussions with media production companies in UK, such as CTVC (CTVC, 2016), Visualise (Visualise, 2016) and

British Telecom’s Media & Broadcasting (BT Media & Broadcasting). CTVC is a media production company that indicated their interest for new ways of producing immersive and interactive media solutions for educational, motivating, and behavioural change purposes. Visualise, on the other side, is a 360-degree video production company creating content and interactive applications for advertising purposes and has expressed the necessity of interaction design guidelines specification targeting 360-degree immersive video experiences production. BT Media & Broadcasting expressed interest of enhancing interaction in 360-degree immersive video, enabling smooth transitioning from scene to scene and engaging audience with content.

1.3 Research Methodology

To be able to overcome the challenges introduced in 360-degree immersive video design and address the objectives of this PhD research, a systematic research methodology has been followed. The methodology is formed by six main processes:

P1: requirements analysis and challenges specification;
P2: design process analysis incorporating factors affecting user experience;
P3: experimental procedure and prototypes design;
P4: utilisation of evaluation methods and data collection tools;
P5: data classification and analysis;
P6: results interpretation and design guidelines specification.

Those 6 processes are further analysed below also providing a justification on how they leaded to the fulfilment of the 4 objectives of the project.

P1: At the first stage, an analysis of the user requirements and challenges imposed by this new technology took place. The analysis was based on literature review of related work providing insights in user needs and design implications and on informal survey involving media production and broadcasting companies in the UK. This process served the first objective (OBJ1) of the study.

P2: Next, the design aspects that should be taken into consideration were thoroughly analysed followed by a specification of factors that affect the provision of immersive and engaging experiences. This process concluded with the specification of the overall design process that should be followed for 360-degree immersive video solutions which addresses the second objective (OBJ2).

P3: To evaluate the contribution of the design methodology and techniques identified in addressing the needs of 360-degree immersive video users, an experimental procedure was designed involving prototype application design and development (specifically two applications were built). The protypes design analysis addresses the third objective (OBJ3). The designed prototypes were subjected to user studies broken down in two different phases. This is due to:

- the large number of design techniques and factors that needed to be assessed;
- the requirement for isolating the techniques and methods by designing different scenarios of application, and;
- the need of recruiting a significant number of users in the process whose interactions with the technology needed to be observed.

P4: Dedicated tools and methods for the prototypes' evaluation have been used targeting the collection of quantitative and qualitative data related to the assessment of the achieved level of immersion and engagement (complementing OBJ2 & OBJ3).

P5: A rigorous method was also followed for the classification of the data and its analysis to allow results interpretation and comparative assessment (complementing OBJ2 & OBJ3).

P6: This method assisted the derivation of a set of design guidelines to be followed by 360-degree immersive video producers and developers (complementing OBJ2 & OBJ3).

The final research objective (OBJ4) was therefore addressed as a result of P4, P5 and P6.

1.4 Research contributions to Knowledge

This research project has managed to introduce four key contributions in 360-degree immersive video applications design.

1. **Six key challenges in designing engaging 360-degree immersive video experiences**

Through a systematic study of 360-degree immersive video technological limitations and design implications, a set of six key challenges in the area has been initially defined. Those challenges are further described in Section 4.2.

2. A systematic design methodology in 360-degree immersive video solutions

Aiming to overcome those challenges, a systematic design methodology has been introduced for designing new forms of immersive solutions based on 360-degree video resources that could serve the purposes of immersive education, cultural heritage, and entertainment. Therefore, the results of this work contribute to the knowledge in the area of HCI and more specifically provide an extension to the State-of-the-Art (SoA) in the fields of games studies, interaction design, VR technologies, education and multimedia computing.

This methodology is summarised in the form of a framework which provides a set of methods and techniques that could be followed at each stage of the design process and are suggested based on the factors related to user engagement, immersion and motivation. This is **the immersive Video Design framework (iVID),** whose purpose is to systematically guide the designer to the adaptation of appropriate techniques and he definition of methods and processes that can effectively address the application goals aimed to be achieved. The innovative aspect of the iVID framework is that it provides a holistic approach in guiding the design of 360-degree immersive video applications by addressing a series of key aspects considered crucial for providing engaging experiences and not focusing on resolving only a specific interaction challenge as targeted by previous approaches in the literature. Design techniques and processes defined through the iVID framework methodological steps and their categorization (see Chapter 4) have been applied to a two-phased testbed evaluation to extract guidelines by assessing their performance against immersion, engagement and usability (see Chapters 5 & 6).

3. Two interactive and immersive 360-degree video prototypes

The key research instruments for this work are two interactive and immersive 360-degree video prototypes that apply different interaction styles and techniques in a series of use case scenarios. Those two prototypes served as case-studies for the evaluation of the iVID framework following a two-phased study approach also providing a guide for 360-degree immersive video developers. The collected quantitative and qualitative data from the two different studies are also available for further analysis by the HCI community. More specifically, researchers and professionals in the area of VR and games design are expected to benefit from the evaluation of the user experience offered by the two prototypes and the assessment of the techniques applied, introducing a new area of further research and innovative business models' development.

4. **Twenty-three (23) design guidelines for 360-degree immersive video application**

A set of design guidelines have been extracted based on the two studies' results analysis and interpretation. Those design guidelines refer to the design aspects and techniques introduced by the iVID framework. Multimedia designers and media production professionals could be benefited with their application in producing engaging new forms of immersive media.

1.5 Publications

The challenges identified at the first stage of the research have been published and presented at the 2nd International Workshop on Virtual Environments and Advanced Interfaces (VEAI 2016), within the 15th International Conference on Ubiquitous Computing and Communications (IUCC-2016), with the title "Engaging immersive video consumers: Challenges regarding 360-degree gamified video applications" (Argyriou et al., 2016).

Based on those, a prototype architectural framework for developing such applications has been introduced and specified. The framework covers all required steps from the production of the media resources that need to be integrated up to the delivery and running of the ready application using a VR headset device. As a next step, a potential use case scenario has been introduced and described followed by the creation of a related prototype 360-degree immersive application. The application design has followed the preliminary development architectural concept and has been presented to the 3rd Annual International Conference of the Immersive Learning Research Network, Coimbra, Portugal, 26 - 29 June 2017 (Argyriou et al., 2017).

The application has been showcased as a demo to the research community as depicted in Figure 1. 1. Initial feedback on the demo application testing by the attendants has been recorded in order to form the design requirements in that area.

Figure 1. 1 Demo showcase at iLRN 2017

A journal paper has also been published. The work outlined is about the first phase studies results, the prototype design to serve a Cultural Heritage (CH) tour and the preliminary list of design guidelines extracted. This work will be published under the title “Design methodology for 360-degree immersive video applications: the case study of a cultural heritage virtual tour” in Special Issue of Personal and Ubiquitous Computing Springer Journal on "Virtual and Mixed Reality in Culture and Heritage" (Argyriou et al., 2020).

1.6 Thesis structure

This thesis is outlined in seven chapters.

The next chapter, chapter two provides a review of the immersive technology field starting with the VR background and definitions, current equipment to support immersive experiences and new forms of immersive fields such as the XR (a term used from combining VR, Augmented Reality (AR) and Mixed Reality (MR)) and 360-degree video. A presentation of formal frameworks for interaction design is provided starting by analysing Bowman & Hodges (1999) research work that has driven the development of our systematic methodological approach for the case of Immersive Video Design (iVID framework). Other frameworks from the literature for the case 360-degree immersive video are also presented and compared to our approach. The design aspects of narrative, interaction provision and gaming are analysed and their benefits to the user experience are recognised. A reference to the role of virtual actors in VR is also provided as an element of design that could be applicable to immersive video. Recent work and developments in the area of 360-degree video are described followed by an identification of the open issues recognised for further research.

Chapter 3 describes the problems identified in the area of 360-degree immersive video applications design and the implications and design issues that this technology imposes. Next, the overall research design is outlined. The chapter concludes by describing the methodological approach followed in addressing the targeted objectives of this research study.

Chapter 4 provides a requirements analysis and an analysis of the challenges identified in designing 360-degree interactive video applications, which is the first contribution of this study. A thorough analysis of the second contribution of this study follows through the specification of a systematic design framework for 360-degree immersive video, the iVID framework. The analysis starts with a specification of the two main design layers for this technology and the factors that should be considered in immersive and engaging experiences design. Next, a categorization of the potential design techniques that are related to the aspects of each design layer is provided. At the end, the iVID framework and its six stages are presented as a concept incorporating the outcomes of the previous methodological analysis.

Chapter 5 describes the first phase studies of this research and its outcomes, which is a preliminary set of design guidelines for 360-degree immersive video. It analyses the design process followed for creating the first study research instruments and it presents and justifies the overall study design and experimental conditions. A thorough analysis of the collected data is provided followed by a presentation of the extracted preliminary list of design guidelines.

Chapter 6 describes the second phase studies following the same structure as for the first one. The second phase studies deal with the evaluation of design aspects and corresponding techniques that have not been covered at the previous stage concluding with a complementary list of design guidelines.

Chapter 7 discusses how the objectives of this research have been addressed by summarising the key contributions of this PhD research. It details the limitations of this work and the targeted communities impacted by the research output. The chapter concludes by listing future directions of this PhD research.

Chapter 2

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2 Immersive technology

This chapter describes the background knowledge for this research project and provides details on relevant research works in the area of Immersive Technology.

It starts by defining VR and current equipment to support such experiences as also new areas dealing with immersive experiences such as the 360-degree video. An analysis of formal approaches for interaction design is also presented and related to our work. It introduces important design aspects and methods that should be considered when aiming to providing engaging and interactive experiences. It argues the importance of narrative design, interaction and gamified design and the way virtual actors contribute to immersion and communication.

A discussion follows on the current developments in the area of 360-degree immersive video and the open issues that need to be addressed though further investigations. The direction of this research is summarised at the end.

2.1 Virtual reality history and definition

The term Virtual reality (VR) has been initially introduced by computer scientist and founder of the Visual Programming Lab (VPL) Jaron Lanier in 1987. That was the year that this research field got its official name. Research in the area of computer-generated simulations with 3D graphics and realistic interactions has started in mid 1950s with the first attempt introduced by cinematographer Morton Heilig as the Sensorama simulator, patented in 1962 (Heilig, 1962). Sensorama technology was intended to provide a multisensorial film experience incorporating stereo speakers, a stereoscopic 3D display, fans, smell generators and a vibrating chair to an arcade-style theatre cabinet. In 1983, the term “artificial reality” was assigned to computer-generated environments that responded to the people in it by Myron Krueger, a computer science researcher at the University of Wisconsin, considered as on the first virtual reality pioneers, who developed a series of such innovative experiences starting at 1969 (Krueger, 1983).

VR is a multisensory experience relying on systems combining 3D graphics, stereoscopic rendering, head-tracked displays, hand/body tracking, and binaural sound (Gigante, 1993). It is an experience that requires advanced interfaces and specialised input and output devices, such as data gloves and head movement trackers and displays, to simulate in real-time a realistic way of interaction with a computer-generated 3D graphics simulation (Burdea & Coiffet, 2003).

2.2 VR headset devices

The first headsets development attempts as precursors of today’s head-mounted displays (HMDs) appeared in 1960s through Morton Heilig’s Telesphere Mask (Heilig, 1960), which provided stereoscopic 3D and wide vision with stereo sound but with no motion tracking. Comeau & Bryan (1961) developed the Headsight, a helmet with a video screen for each eye including a magnetic motion tracking system linked to a camera, but still lacking computer simulation. Ivan Sutherland (1968) was the first to introduce a a head mounted display in 1968, named “Sword of Damocles” which was connected to a computer and able to generate primitive graphics.

Sega and Nintendo presented later on their first VR headset consumer devices for gaming experiences with no commercial success though mainly due to low quality graphics. Sega released the Sega VR-1 motion simulator arcade attraction in 1994 that could track head movement and display 3D polygon graphics in stereoscopic 3D. The Nintendo Virtual Boy or VR-32 was a 3D gaming portable console in the form of a headset connected to a joystick, released in 1995, able to display 3D graphics but only in red and black colours.

During the past few years a significant number of VR device headsets, head-mounted displays (HMDs) for immersive VR, based on PCs or mobile devices by different technology providers have been introduced to the market promising to facilitate immersion in VR experiences. Such headset devices with integrated motion tracking allow their users to look around a virtual space by simply moving their head giving them the sense as if they are actually there.

Those VR devices as shown in Figure 2.1 can be split into two categories: a) tethered and b) mobile.

a. Tethered HMDs

b. Mobile HMDs

Figure 2.1: VR Devices – HMDs 2017

Tethered headsets like the Oculus Rift (2016), HTC Vive (2016), and Sony’s PlayStation VR (2017) require a cable connection with a PCs or a game console in the case of Playstation. Mobile VR headsets are devices with two lenses (right & left) requiring a smartphone to offer a VR view by splitting its screen view in two for your eyes. Such devices are Google’s Daydream (2017), its latest release after the successful Google cardboard, Samsung’s Gear

VR (2017) and many others. The connection with a cable in tethered HMDs restricts the user’s movement but the use of a high-quality display along with built-in sensors and camera trackers and processing power of a computer can offer a better experience for demanding immersive applications.

The cable makes them a bit unwieldy but putting all the actual video processing in a box you do not need to directly strap to your face means your VR experience can be a lot more complex. The use of a dedicated display in the headset instead of your smartphone, as well as the use of built-in motion sensors and an external camera tracker, drastically improve both image fidelity and head tracking.

Besides those popular VR devices there are also a huge number of other headsets with similar capabilities in different prices indicating huge benefits for the VR industry. It is believed therefore that experiences produced by such kind of devices will open up a market for several other industries in areas such as immersive entertainment, rehabilitation, teleconferencing, online shopping and social networking (Parkin, 2016).

2.3 Extended Reality (XR)

Extended Reality or XR (2018) is a new term in the area of immersive experiences design that followed the new VR devices release and deals with all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. XR therefore consists of technology-mediated experiences combining digital and biological realities. XR technology includes a wide spectrum of hardware and software such as sensory interfaces, applications, and infrastructures, which can enable the content creation for Virtual Reality, Mixed Reality, Augmented Reality or Cinematic Reality and is an area that falls in their interpolation as depicted in Figure 2. 2 below. By using XR technology, users can generate new forms of reality by bringing digital objects into the physical world and bringing physical world objects into the digital world. 360-degree video experiences design falls somewhere between the Cinematic Reality and the Virtual Reality in the area of XR.

XR refers to the entire spectrum spanning from "the complete real" to "the complete virtual" in the concept of reality–virtuality continuum introduced by Milgram et al. (1995). XR lies in the extension of human experiences especially relating to the senses of existence (represented by VR) and the acquisition of cognition (represented by AR) a connotation that is still evolving due to the continuous development in the human–computer interaction area.

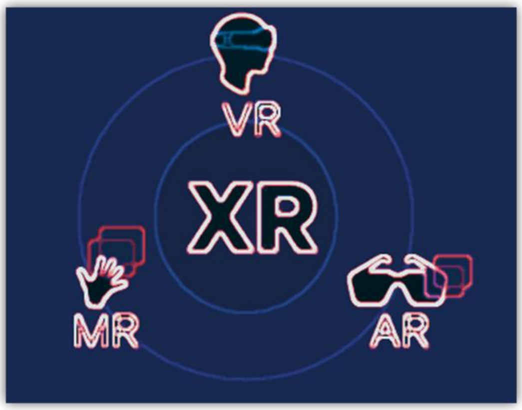


Figure 2. 2: Extended Reality XR (Source: medium.com)

2.4 Immersion definition

There are two kinds of pleasure that users of interactive applications enjoy; immersion and engagement (Douglas et al., 2004).

Immersion is a term arousing from the area of games referring to the feeling of gamers of “loosing themselves” in the virtual world of the game, being distracted from the real world and have the sense that they are actually being part of that virtual experience. More specifically, designing immersive experiences refers to the technical means that are used in order to give the user the notion of presence which relates to the perception of feeling present in a non-physical world (Slater & Usoh, 1993). There are two key characteristics of games that facilitate immersion and can be grouped into two general categories:

- those that create a rich mental model of the game environment, and;
- those that create consistency between the several elements of the environment, such as the game objects, the virtual actors, the interface elements etc. (Wirth et al., 2007).

To support the creation of a rich mental model in immersive experiences, a cognitively demanding environment, that triggers the user’s thinking and understanding of what is going on in the scene, should be designed. Interesting stories followed by challenging tasks attract the user's attention and make the game world believable.

In order to maintain consistency when designing immersive gaming experiences, all game elements used should be consistent to the virtual environment (Madigan, 2012). In more detail, most important is that there are no incongruous visual cues in the game world like for example heads up displays, tutorial messages, distractive notifications, advertisements etc. Moreover, the behaviour of virtual characters and objects in the game world should be believable, meaning that they should behave like you would expect them to in the real world.

Consistency in the gaming experience can be also achieved through the design and integration of interaction models that do create an unbroken presentation of the game world. Game menus and informative texts should not make the game world disappear. The design of the game's user interface (UI) should be non-distractive avoiding messages with long text and colours that will distract the player from the gameplay.

Ernest W. Adams (2004) has defined three main types of immersion:

- **Tactical immersion**: Tactical immersion involves skills demonstration and enhancement in performing tactile operations. It is cognitively demanding and usually experienced in games demanding fast, immediate, and intuitive decisions. The subjects are trying to be successful in the experience by perfecting their moves.
- **Strategic immersion**: Strategic immersion refers to mental challenging of the players to choose the most profitable action among several possibilities offered, like playing a chess game. Its more slow-paced but requires observation, deep thinking, and logic driven decision-making in order to find the optimal next action.
- **Narrative immersion**: Narrative immersion is achieved through the users being invested in the story presented, as a similar feeling experienced while reading a book or watching a movie. Only good and strong storytelling experiences that create empathy to the subject can lead to such kind of immersion.

Moreover, based on the results of a qualitative study conducted by Brown and Cairns (2004), three distinct levels of immersion have been defined based on the degree of user's involvement in the experience:

Level 1: Engagement: The first level of immersion is defined as “engagement” lying on the user’s motivation to spend time and effort to become familiar with the game’s rules and controls.

Level 2: Engrossment: The second level of immersion is mentioned as “engrossment”. In such a state, the game design and combination of game elements affect the user’s emotions making them be less aware of the surroundings and completely familiar with the controls.

Level 3: Total immersion: The final level is that of “total immersion” where the sense of presence is what characterises the overall experience leaving the user as being cut off the real world.

Finally, we can summarise that there are three main features that indicate immersion as per Jennett et al. (2008):

- users lack time awareness: they do not notice the amount of time that has passed;
- users loose reality awareness: they do not notice things happening around them in the real world;
- users are involved and have a sense of being in the task environment: all their attention is focused on the virtual world activity.

2.5 360-degree immersive video

Videos of 360 degrees is not a new form of media. 360-degree murals or panoramic paintings appeared first at the nineteenth century with the aim to fill the viewer’s entire field of vision giving the illusion to the observer of being present at the presented historical event or scene. Charles Wheatstone’s research demonstrated in 1838 two 2D images seen from each eye are processed by our brain as a single 3D visualisation. Stereoscopic images or photos when viewed side by side through a stereoscope give the viewer the sense of depth. View-Master was the first released stereoscope device in 1939 for “virtual tourism” purposes and of which the design has driven the creation of Google Cardboard and VR headset devices for mobile phones (Virtual Reality Society, 2016).

360-degree videos as a form of immersive experiences became popular following the release of the low-cost VR headsets for consumer purposes that could support a wider field of viewing range and stereoscopic display. An HMD allows the user through head movement to choose its own field and direction of view (FoV) simulating a real-world viewing experience. The potentials for immersive experiences provision by 360 videos, led YouTube to provide support for such media upload and display in March 2015 through its official website and Android application (Wired, March 2015). Facebook followed in September of the same year reaching 1 million uploads by March 2017 (Facebook Newsroom, March 2017). Changing the field of view of a 360 video can be done through mouse dragging on a website app when experienced through a PC or laptop or touch and drag gestures on a mobile device or tablet. 360-degree video mobile applications take advantage also of the gyroscope and accelerometer sensors of the smartphone allowing camera view rotation based on the change of the device's orientation.

A new field of VR experiences was also introduced, that of Cinematic Virtual Reality (Nielsen et al., 2016). The difference between Cinematic VR and 360-degree video applications lies in the better sense of presence, accessibility and camera motion offered by the former due to the use of VR headset devices. 360-degree immersive video allowed viewers to become more active by choosing their own point of view to experience a scene and not just following the director's frame shot, providing in this way a more personalised and realistic experience (Ellicom, July 2017). 360 video and CGI VR storytelling experiences allowed the producers to create longer lasting impact to the audience by making them feel like taking part in the action and the narrative (The Guardian, December 2015). Oculus (owned by Facebook) got into VR film production through the launch of the Oculus Story Studio that has released three VR films by now and provides advice in this technology development (Oculus Story Studio, 2016). VR cinema professionals are focusing also on creating semi-interactive experiences that fall between games design and film production with the aim to create more engaging experiences (The Guardian, December 2015).

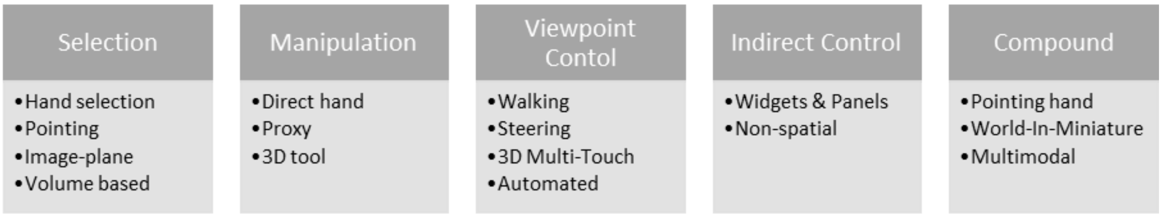
Cinematic VR has also moved effectively towards the production of storytelling 360-degree films introducing a new way of offering immersive experiences. Within (2016) is a company that has released a series of short 360-degree films that have been seen in more than 40 countries and have been translated in 15 languages. This is a successful example of how communicating stories can raise awareness as the user feels like he is actually taking part in the story. TV broadcasters, news channels and journalists are also looking of new forms of immersive media and live events broadcasting in VR as they allow the users to feel that they participate as spectators in a broadcasted event making the overall experience more immersive and engaging (Hayden, 2016). BBC R&D (2017) has also invested on the 360-degree video and VR research for broadcast solutions production by forming its Reality Labs in 2014. The lab's focus is to provide ways and knowledge in creating immersive video experiences based on BBC content, investigating therefore on the use of 360-degree video and VR technologies for journalism, narrative and educational content production. Their 360-degree immersive video productions though are more passive than interactive.

Best practises in this field have also been shared by Cinematic VR production companies. Moreover, a simple guide is available online on how to produce 360-degree videos (BBC Academy Guides, 2019). Chris Milk and Aaron Koblin of Vrse summarise that VR gives the feeling to the user of controlling what they see by experiencing the film production as a first-person perspective. Transitions in VR and 360 videos are also different as we can avoid distractions by flat cuts though the embedding of smooth wipes and fades. Actors also play a significant role in the experience and new techniques of directing should be investigated as the audience can perceive better their movements and be magnified by those when being closer. Finally, camera motion should be carefully designed as rotation with VR headsets is handled by the user and any additional movement can lead to nausea or sickness effects.

2.6 Formal interaction design for Immersive Virtual Environments

The ability to interact and get feedback on your actions from a Virtual Environment is a key aspect of VR applications. Interaction offered by VE is usually viewpoint motion control, selection and manipulation of virtual objects supporting the requirements for user control of the system, travel through the environment, and information retrieval (Bowman et al., 1998, Bowman & Hodges, 1999).

A classification of interaction patterns in VR followed by a representative list of techniques has been also introduced by (Jerald, 2015) as depicted in Figure 2. 3.



Selection	Manipulation	Viewpoint Contol	Indirect Control	Compound
•Hand selection •Pointing •Image-plane •Volume based	•Direct hand •Proxy •3D tool	•Walking •Steering •3D Multi-Touch •Automated	•Widgets & Panels •Non-spatial	•Pointing hand •World-In-Miniature •Multimodal

Figure 2. 3: Interaction patterns and techniques introduced by [Jerald, J., 2015].

Interaction techniques are methods of performing an interactive task through an interface that could be a hardware component; a software component displaying information or instructions for controlling the environment or being transferred to another virtual location; and metaphors or concepts (Bowman et al., 2004).

Interaction in 3D imposes several challenges though as people find it difficult to understand the 3D space affordances and perform actions freely (Herndon, 1994). Task analysis and classification is an important methodology valuable for decision making processes when designing interaction. Consideration should be given to the device targeted and its capabilities and ways of providing user actions input as also to the trade-off between the interaction technique design and the environment design (LaViola et al., 2017).

Another important element of interaction in VE is the provision of a virtual world reference frame as a significant way of giving feedback to the users on their current location and its reference to the VE. This kind of information can be effectively introduced to the user through the integration of cognitive maps. A cognitive map introduced first by (Tolman, 1948), is actually a mental model serving information decoding, acquisition and recall about the relative locations and attributes of phenomena in a metaphorical spatial environment.

2.6.1 Bowman & Hodges (1999) framework for interaction design analysis

Bowman & Hodges (1999) have a introduced a rigorous methodology for the design and evaluation of interaction techniques for immersive VEs based on a formal task analysis and categorization of the techniques, using also multiple performance measures. This work has been an inspiration for the specification of our systematic methodological approach for the design of immersive 360-degree video-based applications (see Chapter 4).

Three main VE interaction tasks have been studied in the framework introduced followed by a list of corresponding interaction techniques: viewpoint motion control, selection, and manipulation. Formal characterizations of those universal interaction tasks and formal taxonomies and categorizations of interaction techniques for those tasks have been developed. Those characterizations were used to introduce novel techniques that were subjected to experimental analyses leading to their performance evaluation against the interaction requirements set at the beginning of the design process. Formal frameworks provide insights on the advantages and disadvantages of existing techniques and a more systematic approach to create robust and well-performing new techniques according to knowledge gained through evaluation studies. Figure 2. 4 below depicts the overall methodological framework and its processes for interaction design for immersive VEs introduced by Bowman & Hodges (1999).

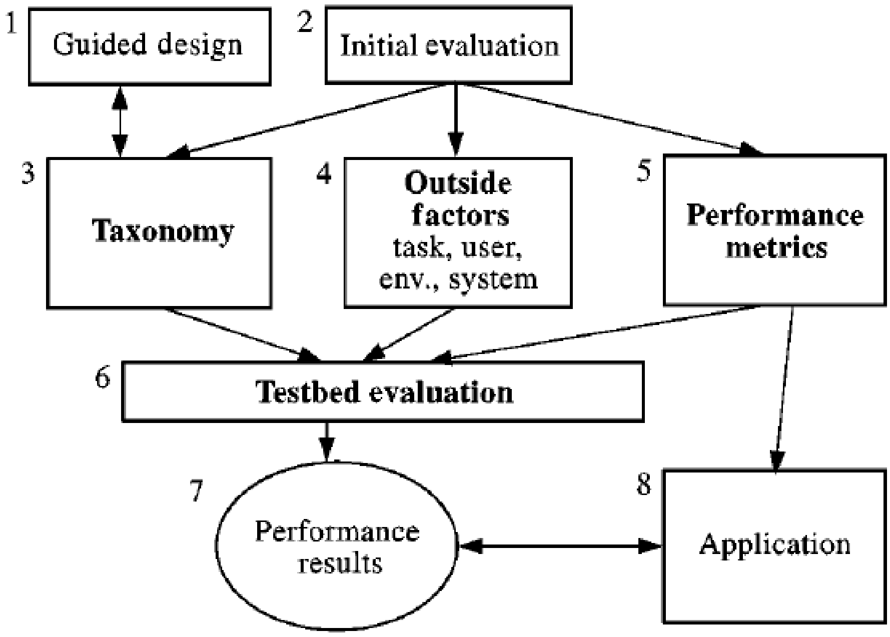


Figure 2. 4: Bowman & Hodges (1999) design, evaluation, and application methodology for interaction techniques for immersive VEs

In our work we have also defined taxonomies for categorizing design aspects and techniques for the case of immersive 360-degree video-based applications (as guided design formal approach) driven by requirements analysis (see section 4.1) and mapped to factors related to immersion and engagement (see sections 4.6, 4.7, 4.8). This formal analysis of the design process assists the definition of design techniques whose performance was evaluated though testbed experimental studies (see Chapter 5 & 6). The outcomes of the testbed evaluation procedures were a set of design guidelines for the application of the techniques based on quantitative and qualitative results analysis (see sections 5.7 & 6.7). Of course, we cannot claim that we have listed all possible tasks and techniques through our taxonomies but provided a starting point analysing the ones conceived though our own experimentation and literature review.

2.6.2 Frameworks for 360-degree immersive video experiences

There are a few research works found in the literature dealing with the specification of frameworks for creating 360-degree immersive experiences.

TogetherVR is a framework introduced by Prins et. al (2018) that deals with the development of social collaborative web-based 360-degree video experiences providing an analysis of the hardware and front-end and back-end system components and web frameworks (like WebVR, AFrame, three.js, WebRTC, WebAudioAPI, WebGL, soket.io, Angular, Dash) that should be used. Another framework that deals with 360-degree video streaming has been introduced by Nguyen et. al (2019) presenting a tile-based viewport-adaptive streaming architecture addressing bandwidth issues.

The difference to our approach is that those frameworks focus on the specification of development guides addressing a specific technical challenge or case study such as the streaming of such experiences. This research work and the framework introduced in Chapter 4 introduces a holistic and more rigorous methodology for the overall user experience (UX) design incorporating several aspects, techniques, and factors. The elements of the framework and the process followed is driven by the literature review of the interaction analysis and navigation in VR, narrative and storytelling experiences design, gamified design, and the use of virtual actors. A literature review for those aspects is provided in the following sections.

The methodological design framework proposed (see Chapter 4) provides a specification of the way those aspects should be studied in terms of factors targeted to extract techniques and guidelines that can lead the design of immersive and engaging experiences. It deals with which aspect/method, how and at what stage of the overall design procedure should be studied followed by a set of design guidelines for their application based on experimental studies (see Chapters 5 & 6).

2.7 Narrative and Digital Storytelling

Storytelling is a social interaction method between humans in sharing stories by conveying techniques on the way a narrative unfolds. Digital storytelling relies on the use of digital technology as a medium such as digital media (Shin and Park, 2008). It can be found in several forms depending on the digital media used such as interactive web applications, digital videos, or games and even VR experiences. Digital and more specifically VR storytelling has proven to be an effective and engaging way of educating students (Robin, 2008). Han (2007) pointed out that digital storytelling is also an important aspect in the design of edutainment learning experiences. Digital storytelling is characterized also by flexibility as it is related to the design of non-linear stories using digital media technology (Gregori-Signes, 2008).

Narrative design is defined by a clear structure involving agents that play a significant role in the story determination (Hinyard & Kreuter, 2007). Adams (1999) states though that *"Interactivity is almost the opposite of narrative; narrative flows under the direction of the author, while interactivity depends on the player for motive power*.

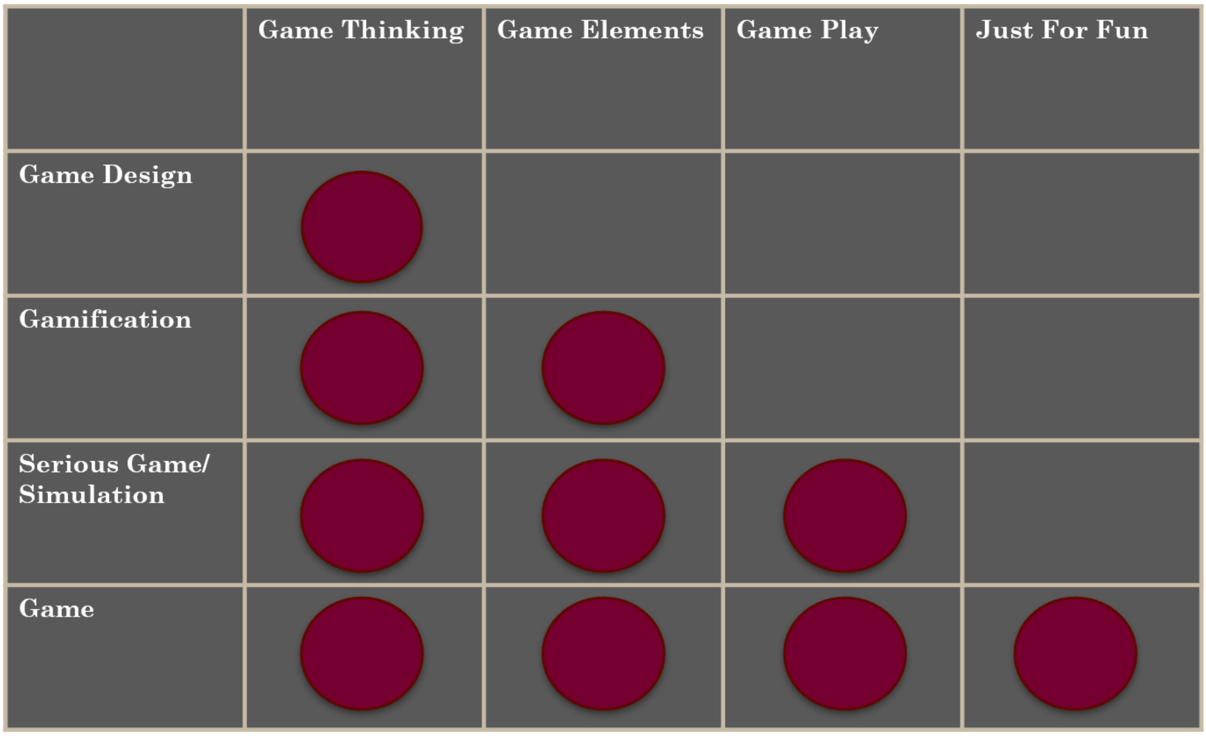
Therefore, digital storytelling techniques are promising for effective edutainment immersive experiences design. The investigation of efficient methods in the design of the narrative and the interactivity parts of storytelling is considered crucial for immersive 360-degree video experiences.

2.8 Gamified design

2.8.1 Games design and gamification

The concept of gamification was introduced several years ago (O’Brien, 2010) as the use of game design elements in non-gaming applications and services to enhance the level of user’s engagement and motivation. In contrast to serious games design that refers to complete gaming applications for non-entertainment purposes and has been widely used for educational and professional training purposes, gamified applications are not actually a game, but refer to the merely incorporation of game elements. Certain game elements when integrated in right combination can enhance the level of player’s engagement (Reeves &

Read, 2009). Narrative context, time pressure, leader boards, badges, level-systems, competition under strict rules, achievements and rewards are some of the mostly used game elements that are proven to drive the design of playful experiences (Gamified UK, 2016). According to Andrezej Marczewki's diagram (2013) as depicted in Figure 2. 5, the main differences between the terms game design, gamification, serious games or simulations and a complete game are based on the design goals and intentions which are game thinking, incorporation of game elements, game play or design just for fun experiences.



	Game Thinking	Game Elements	Game Play	Just For Fun
Game Design	●			
Gamification	●	●		
Serious Game/ Simulation	●	●	●	
Game	●	●	●	●

Figure 2. 5: Differences in Terms (game design, gamification, serious games, and games)

2.8.2 Serious games

The term "serious games" was used first by (Abt, 1987) to differentiate between games for fun and games for learning. More specifically, Abt's definition is the following: "*Reduced to its formal essence, a game is an activity among two or more independent decision-makers seeking to achieve their objectives in some limiting context. A more conventional definition would say that a game is a context with rules among adversaries trying to win objectives. We are concerned with serious games in the sense that these games have an explicit and* *carefully thought-out educational purpose and are not intended to be played primarily for amusement.*”

In 2003 (Prensky, 2003) defined the benefits from the use of digital games in education along with their cognitive aspects and later on in 2005 they have been further explored (Gee, 2005) with the identification of 36 learning principles in the use of video games. Further research studies (de Freitas, 2006; de Freitas & Neumann, 2009; Egenfeldt-Nielsen, 2005; Prensky, 2006; Squire, 2004; Squire & Jenkins, 2003) have shown that serious games can be a very effective instructional tool and can assist learning by providing an alternative way of presenting instructions and content on a supplementary level. Games in general and gamified applications can trigger student motivation and interest in a specific subject providing enhanced learning effectiveness. In recent years, huge effort has been made towards the development of educational gaming experiences and the exploration of their advantages for learning by introducing a set of possible educational scenarios using leaderboards, badges, level-systems, geolocation services, achievements and rewards (Erenli, 2012). Transmedia storytelling learning is also another valuable approach which refers to the direct involvement of the user in the game’s story taking advantage of elements such as the Internet, serious games, video, social media, graphic novels, machinima, blogs, and alternate reality gaming to enhance the audience engagement (Raybourn, 2014).

There are also many Commercial Off The Shelf (COTS) games that are being considered for education. A few COTS games already being used in the classroom are Civilization (history), Age of Empires II (history), CSI (forensics and criminal justice), The Sims 2 (social and personal education) etc. Latest types of serious games are based also on Virtual Worlds with an emphasis to supporting and enhancing interactivity and immersion. VR Serious Games are used to support learning in cases where there is need for overcoming the barriers of time and space for geographically distributed users.

Serious Games design techniques and VR technologies support the creation of realistically reconstructed 3D environments supporting immersion. It is believed therefore that strong emphasis should be given to the analysis and research of serious games techniques that need to be combined with new forms of VR technologies in order to support also educational experiences. A suggestion arising from that approach is that the combination of immersive

360-degree media and serious games techniques could define innovative learning models leading to more engaging and motivating learning solutions.

2.8.3 Game elements integration to support user engagement

There is a list of around fifty different game elements and techniques specified through all these years, but the most common ones still remain the use of points and scoring, leader boards, badges collection and progress bars. While all those game elements are significant for the design of effective gamified experiences, the enhancement of the user’s engagement and motivation feelings should be investigated through the experimentation and evaluation of more complex techniques and richer elements combinations.

Below, a list of such elements and game techniques is presented and described in more detail (Wilson et al., 2009, Kapp, 2014):

1: Creation of Mystery in the Story

Stories that are based in mystery arouse the question to the player of what happened and why this happened. The experience makes the player curious to reveal unknown hints by analysing known information. Not all the information required are revealed to the player from the beginning. Mystery is used to design game stories encouraging the player to explore the environment, look for clues and analyse them in order to come up with knowledge that will help them proceed in the game.

2: Action from the start

The player should start the overall experience with action, meaning that they must do something from the beginning in order to proceed. The use of short tutorials, introduction of objectives that need to be analysed or understanding of the game affordances and rules from the beginning is a good way of putting the player directly to take action.

A good practice is to start by asking from the player to take a decision immediately, for example if they are going to move to specific direction or decide an action plan. Immediate action and interactivity engage the user.

3: Challenges integration

Challenges must be introduced continuously to the players, from the beginning up to the end of the gamified experience. Every human is motivated by challenges. Tasks that require deep thinking and complex information analysis motivate and engage the player further to explore the game and its environment. Step-by-step instructions and easy to solve riddles or simple questions can discourage the player.

4: Being at risk

The player must be introduced at risk from the beginning of the experience. A wrong decision could make them loose significant amount of points or even start from the beginning. When feeling at risk the player becomes more careful and attendant focusing on the completion of a task and therefore being engaged to the experience.

In case of a bad decision or a mistake the player could be requested to solve additional riddles, follow more difficult paths, do something again like in a real-life scenario. Limited number of attempts, time limits that could lead to having to start over and try again make the player more efficient and motivated.

5: Uncertainty of outcome

Related to emotions aroused form being imposed at risk is the situation where the player cannot guess the outcome of their actions. They should not be aware of what will happen to the next level of the game, what new challenges they will be introduced, what would be the next level of difficulty. Even if the game is based on the use of simple questions and answers, the next level of difficulty should be uncertain. They could have an opportunity to get an easy or a difficult task to accomplish as a next step.

6: Opportunity for mastery

The player should be able to demonstrate mastery within the environment. Through the progress indicators, successful messages, and other mastery visible signs such as a collection of badges the player is motivated to explore more its capabilities and become more motivated.

By being given the chance to apply their newly learned content, asked in different ways, and being able to express their own knowledge by solving a series of difficult problems, once they solve one problem and move on to the next problem of increased difficulty level while being awarded with corresponding badges through the experience they have the feeling of mastery and accomplishment. Even if they fail at the final stage, they still have visible, tangible evidence of their mastery through their own badges.

7: Visible signs of progress

The player should be always aware of how far they have reached. Through the use of badges or by moving to the next level or by being able to unlock a new experience after an achievement is a way of providing them clear evidence of progressing. In the games design we are using progress bars, levels, and coins or points collections to inform the player that they are closer to the end goal.

8: Emotional content

Games should be based in strong stories that can create emotions to the user. The design of the gaming experience must fill a player with emotions ranging from frustration to elation, from sadness to anger to enthusiastic happiness. The overall game design should embrace and encourage human emotions. Strong emotions arouse from strong experiences and are the key to successful and engaging gamified application design.

2.9 Virtual humans' role in VR experiences

Virtual humans in VE may have two different roles; that of the avatar or that of an agent. Avatars are virtual representations of actual human users in a VE while agents are autonomous, and their actions are pre-scripted or driven by artificial intelligence. Both instances can significantly affect the sense of presence to the VE participants through the social interactions they invoke (Slater, 1999, Cauell et al., 2000).

Interactivity with virtual humans relies in visual communication through their virtual activity and virtual body movements (non-verbal behaviour) or in verbal communication. Non-verbal communication refers to communication through the body, through facial expressions, gestures and even gaze interactions (Argyle, 2013). Gaze based interaction with virtual humans has also been studied arguing that the interpersonal distance evolves with mutual gaze engagement (Bailenson et al., 2001).

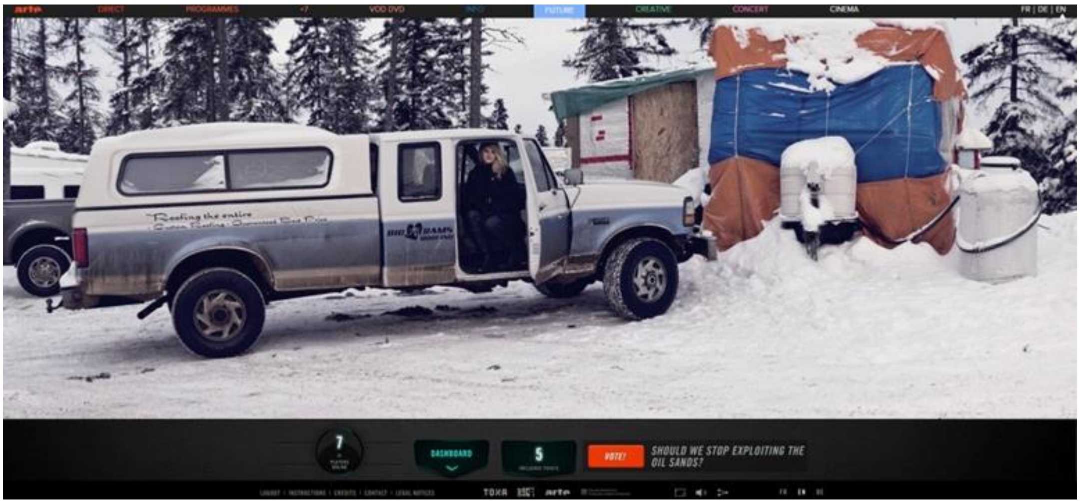
It is important therefore to investigate how humans captured in a 360-video experience can influence the actions and behaviour of the viewers. This study investigates the role of human actors in 360-video towards motivating them to look around in the captured scenes as also increasing their sense of presence in the virtual environment.

2.10 Immersive experiences based on 360 videos

Following the latest technological developments in VR devices and 360 video cameras, there are several immersive and interactive video-based applications that have been released the past few years. Those applications are mainly based on 360-degree video resources incorporating gamified techniques or just creating immersive storytelling experiences.

360-degree video applications have a huge potential of generating highly immersive video environments that surround the user and therefore can lead to the creation of experiences that offer an increased sense of presence (Galloso Guitard et. al, 2012).

A good example of the gamified 360-degree film-based narratives approach has been the award-winning web application of “Fort McMoney” (2016) which is depicted in Figure 2. 6 below. In that case, game mechanics have been successfully integrated with traditional film production in order to engage citizens in actively taking part in the future development of their city (the construction of the world's largest sands reserves in the area of, Alberta, Canada and Athabasca).



SHOULD WE STOP EXPLOITING THE OIL SANDS?

Figure 2. 6: Fortmcmoney an interactive Film-based serious game

In Fort McMoney, the user can select to move in the story through hotspots that are presented at the end of a 360-degree video resource on a static panoramic image or through the user interface buttons at the bottom of its screen. Therefore, through the complex interface and the use of static images that pause the film, the user can be distracted from the actual plot of the presented story and the sense of flow in the game can be lost. Moreover, this application has been designed for the web only therefore it cannot be experienced though a VR headset device such as Oculus Rift which enhances the level of user’s immersion.

Another approach of designing immersive interactive 360-degree video experiences has been introduced through the integration of 360-degree video with hypervideo where links and annotations are integrated in the video in different times and areas of the 360-degree view (Chambel et al., 2011). In this case, innovative navigation mechanisms have been designed and proposed. Those mechanisms, as depicted in the Figure 2. 7 below, are:

- a drag interface to assist panning;
- the view area indicator in the form of a pie chart;
- a mini map with the planar projection of the video, and;
- hotspots indicators and thumbnails highlighting the current scene.

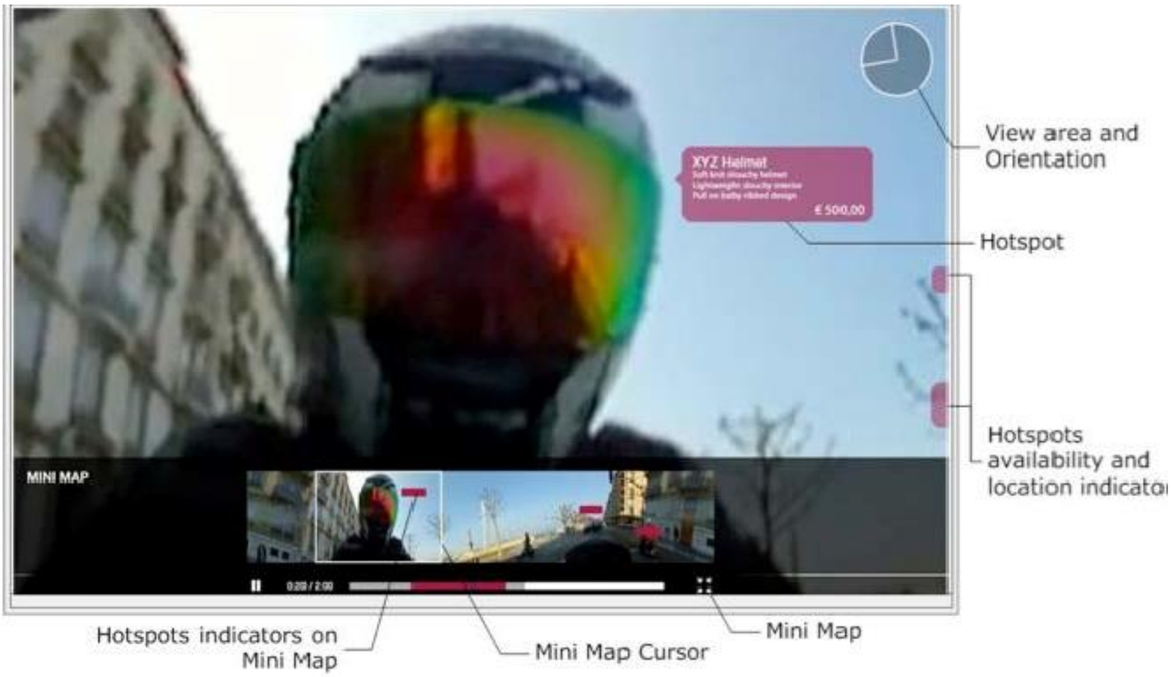


Figure 2. 7: Chambel, et al., HV 360º Player in Mini Map Mode

While this approach addresses some issues of enhancing interactivity and supporting navigation and orientation in 360-degree video viewing on the web, the interface presented is complex and contains lots of information that may distract the user from the main story ending to a not such engaging experience. Chambel, et al., (2011) also points out that research has to be done on enhancing entertainment and user engagement through storytelling mechanisms.

The question though still exists on how these experiences could be designed to be coupled with other devices (mobiles, head-mounted displays) making the experience more interactive and engaging.

2.10.1 360-degree Immersive video applications in Cultural Heritage

Digital storytelling is proposed as an effective way of introducing cultural heritage information (Athenaplus, 2014). Recent studies reveal that beyond digital, immersive storytelling based on experiential media, such as 360-degree videos, is a promising and engaging new form of experiences. As defined by Pavlik (2018, p.49): "*Experiential media forms enable the user to experience stories as a participant in a first-person narrative, rather than merely watch, listen or read the story from a third-person voyeuristic vantage point*".

The work of Ivkovic et al. (2018) presents an interactive cultural heritage application based on 360-degree videos for the Bridges of Sarajevo. Participants were engaged to further explore the story of the seven bridges through the ability to choose on their own the order to experience the provided cultural information. A map interface menu with 3D models of the Bridges of Sarajevo that formed elements to choose and start exploring the application was also integrated. Participants were further motivated to explore all the provided content with the integration of a rewarding mechanism, through the collection of puzzle pieces for each visited bridge, that when completed it allowed them to explore an extra video scene. It also reports that participants felt like they were realistically walking on the bridges when experiencing the video stories. That application though was web-based, and therefore there was no discussion on design considerations for VR headset applications, promising for increasing the sense of presence.

Selmanovic et al. (2018) introduce an immersive 360-degree video application for preserving the bridge diving tradition from the Old Bridge in Mostar, Bosnia and Herzegovina. The users watch 360-degree videos about the history and the diving tradition and answer a series of quizzes on the presented information. It is an effective approach of designing immersive cultural heritage solutions experienced through VR headsets, but it lacks a systematic design methodology formation and evaluation of further motivational and immersion factors that could be considered.

Cai et al. (2018) have reported their assumptions on the comparison of the use of 360-degree video recordings and Virtual Environments in triggering memory of the past. Their study involves the creation of a virtual house with realistic photogrammetric reconstructed objects of the dwellings used daily by local Ningbonese people since the last century. That virtual reconstruction has been compared to a high-resolution 360-degree video showing an old couple cooking food inside a well-preserved house located in Ningbo. In the VR application the users could, by an HTC Vive, interact with the virtual objects through grapping, or opening drawers. Though the 360-degree videos had been experienced passively though a Samsung Gear device allowing only the view rotation based on head movements. The applications have been tested by 21 local participants familiar with the history of the city. The results revealed that the video felt more real exposing the high potential of the medium, though the virtual reconstruction contributed better to familiarity and memory recollections. It is supported therefore that 360-degree immersive video user experience issues are related to the lack of freedom in interaction in such environments which is what the study presented in this paper attempts to address by providing an analysis of design methods for 360-degree immersive video applications.

Another interesting study on the comparison of a VR application to 360-degree media is that of Boukhris et al. (2017). A user study has been conducted to compare a Virtual Reality cultural heritage visit to a 3D model of a Paleolithic cave, the "Grotte de Commarque" located in the south of France with a series of 360-degree pictures experienced through a VR Headset. Viewers could observe the cave and explore it through teleportation mechanisms. The findings of the study reveal a better sense of presence offered by the 3D VR version. The form of 360-degree media used in this study though is limited to 360-degree pictures not video while offering minimum interaction.

None of the studies in 360-degree immersive video applications has experimented with navigation design approaches beyond teleportation, such as moderate motion design with locomotion. The design and effect of human actors / avatars in motivating users' actions and increasing engagement has been studied in the context of immersive VR by Sylaiou et. al. (2019) and Carrozzino et. al. (2018) providing significant insights. It is, therefore, considered important to examine the role of human actors in user motivation for the case of 360-degree immersive video applications.

2.10.2 360-degree immersive video interaction and navigation design

Despite the fact that the 360-degree immersive is considered a relatively new technology there are interesting research works that provide insights on interaction and navigation design aspects.

The most popular element used to provide interaction with 360-degree immersive video displays is the hotspots. Hotspots are embedded graphic icons that could serve different purposes. There are information hotspots that provide textual or visual information about the observed POI and navigation hotspots that support the transition to another video scene (Kallioniemi et al., 2017). In case the interaction provided though HMDs is only gaze-based, hotpots can be programmed to be triggered in dwell-time (by looking at the hotspot for a few seconds).

Other design approaches for guiding the viewers of 360-degree video have been also introduced in the form of more automatic guidance solutions. One such approach is social indicators that refer to automatically changing the user's view direction by analysing gaze data from other viewers (Mäkelä et al., 2019). The analysis of the data is supposed to indicate the areas of interest in a scene. The use of social indicators can be distractive if the change of view happens frequently and viewers would like to have a same experience with people they know and not guided based on unknown audience preferences. The need for investigating methods that can balance guidance and self-exploration is also recognised.

Sheikh et al. (2016) have also conducted studies experimenting with different design techniques for directing the user of 360-degree immersive video. Those techniques are related to the video production process dealing with motion capturing and gestural and audio cues.

Results indicate that visual cues guarantee more the direction of the user’s view in comparison with audio cues. The need for research studies on the design and integration of objects in the virtual scene where video is rendered aiming to guide the viewers is also mentioned.

Sitbon et al. (2019) have experimented on movement and viewpoint direction techniques for 360-degree immersive video solutions experienced though HMDs targeting people with intellectual disability for everyday learning skills scenarios. Through the analysis of their studies results the propose that abstract symbols such as arrows should be avoided and replaced by in-video facilitators for guiding the user’s view, that still videos are best for outdoor spaces transversal and that 360-degree pictures should be first introduced of a familiar environment which reduce the viewer’s anxiety. Their findings though are based on a limited number of participant’s feedback (only 4 users which is even considered not significant for qualitative studies) and refer to specific user characteristics and not the wider audience.

Lin et al. (2017) have also experimented with two ways of assisting the viewer’s focus in 360-degree immersive video. Those are the Auto Pilot and the Visual Guidance. Auto Pilot rotates the user’s view direction in the scene towards predefined areas of interest which is in contrast with Gugenheimer et al. (2016) approach that rotated the viewer’s body in real-life using motorized swivel chair. Visual Guidance refers to the use of visual indicators pointing the direction of the area of interest. While results indicated that Auto Pilot was a more efficient technique in directing the user, the user acceptance relies to their preference on being guided versus self-exploration and the technique should be applied with a specificity to the context displayed and the use case scenario purpose.

Other navigation mechanisms, such as mini maps and view area projections on top of the 360-degree video have been used effectively by Neng & Chambel (2010) but those elements have not been evaluated when experienced through HMDs.

There are also other techniques inspired from real life scenarios that can be incorporated to direct the users as people are engaged by the movement of objects or humans in the scene (named POIs). Probabilistic Experiential Editing is the new term introduced by Google’s VR filmmaking team (Brillhart, 2016) to characterize their proposed VR storytelling creation method. That refers to a technique of using visual and audio cues that become potentially POIs and allow the guiding of the viewer in the VR world by predicting the flow of its attention focus in the developed story.

Suh et al. (2018) experimented with moving viewports and how those affect user's engagement levels and motion sickness. Moving Viewports (MVPs), refer to camera movement and turn to keep the subject in view while recording, while Static Viewports (SVPs), refer to statically placement of the camera in the center of the scene during shooting. Their findings revealed that the use of MVPs has an additive influence on presence while also offset the effect of HMDs on motion sickness. Such promising interaction design approaches are further explored through our studies and also considered in the methodology proposed under the exploration of navigation support through moderate motion design based on MVPs (Section 4.8).

2.10.3 Issues in 360-degree interactive video applications design

The main issues when using 360-degree video for creating immersive applications is the lack of perceptual depth and the limited boundaries of 3D space to navigate and interact with. The 3D VR scenes constitute of video elements mapped on 3D objects, such as spheres, cubes, or polygons. The interaction with the video scene is therefore limited to pan, zoom or tilt or selecting hotspot elements placed on top of the video that could trigger another media resource. To design further interactive tasks, the scenes should be enhanced with other 3D objects and UI elements. The design and positioning of those elements in the video scenes will inevitably hide parts of the video and may even obstruct large segments of it.

Efficient design techniques from the area of VR and games can be applied also to 360-degree immersive video applications dealing with navigation and motions design, location awareness, UI and interaction design. The effectiveness and user acceptance of the design techniques applied for navigating the user to a 360-degree immersive video experience are relative to the context of the application and the user preferences (Lin et al., 2017). It is necessary therefore to provide design guidelines for the applicability and use of each technique.

A preliminary list of six design guidelines has been introduced by Saarinen et al. (2017), for Interactive Omnidirectional Videos (iODVs) under the scope to address the lack of guidelines for practitioners in this area. Those guidelines are focusing in assisting interactivity and navigation. Further studies should focus on elaborating this list and providing a more rigorous specification for their application.

A list of design implications of 360-degree video experiences has been also introduced by Kasahara et al. (2015). Some of those implications refer to:

- experiencing cybersickness when motion provided by the video (such as walking footage) is in conflict with the viewer's motion;
- the need of providing information about the viewing angle of other spectators in shared experiences.

The issue of cybersickness could significantly affect the user experience pointing the need for investigating methods and techniques for motion design in 360-degree immersive video that are comfortable to the viewer.

360-degree video production process should be also further analysed providing ways for non-linear production design of storytelling experiences as users explore 360-degree captured scenes and not 2D scenes as in common video productions. The users view cannot be directed and is expected to change according to the Points of Interest (POIs) location in the 360-degree environment. New methods for the narrative design of 360-degree video experiences should be explored and evaluated.

2.11 Area of research summary

The current state of the art in interaction design is based mainly on common VR design approaches that use 3D graphical representations of the virtual world, virtual actors for simulating a real-life training scenario and 2D video. Nowadays, there are significant possibilities in the area of VR though that could lead to more immersive experiences taking advantage of the massive release of 360-degree immersive video resources and new immersive media display devices. The introduction of 360-degree immersive videos on the other hand, though it has proven to increase the level of immersion in comparison to 2D or 3D video lacks in terms of interaction offered to the viewer. This urges the research on new interaction techniques and design guidelines towards increasing the user’s engagement when experiencing such kind of VR media. Additionally, there is less effort given on the integration of gamified design aspects in 360-degree interactive immersive video and on the evaluation of the quality of the user experience (UX) offered and sense of engagement achieved.

Therefore, what is considered as crucial is to work towards the research of new ways of designing interactive engaging experiences by using 360-degree immersive video technology focusing on the user’s engagement and motivation. Effective interaction design techniques must be identified and applied in order to increase the user’s curiosity and motivation for interaction targeting the introduction of a new way of producing interactive immersive applications. This project’s work focuses on defining, introducing, and evaluating a set of design methods and techniques that promise to increase the user’s engagement by merging 360-degree immersive video technology with 3D/2D graphical elements. A methodological framework is also introduced inspired by the formal design analysis introduced by Bowman & Hodges (1999).

This section provided a review of the VR field and the interaction supported in VE and the benefits of gamified design approaches in navigating the user. This analysis is necessary to be able to derive design techniques from those areas to be explored in 360-degree immersive video applications. The potentials of narrative and storytelling have also been described followed by an explanation of how virtual actors can contribute to the user’s motivation and guidance. An analysis of the current contributions of recent studies in the area of immersive video has been also provided followed by a discussion on the open issues in the design process of 360-degree video interactive experiences.

The goal of the study is to present a systematic methodology for addressing those issues by incorporating applicable design techniques for 360-degree immersive video followed by a set of design guidelines for designers, developers, and content producers.

The following chapter discusses further the problems that this research aims to resolve and the challenges that need to be addressed. It provides an overview of the research methodology starting with the elicitation of requirements for 360-degree immersive video and explaining the approach followed for hypotheses formation and evaluation.

Chapter 3

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3 Research methodology

This research study in the area of 360-degree immersive video has proven to be a demanding and challenging task. By studying the technological affordances in developing 360-degree immersive and interactive video solutions, a list of challenges has been initially defined that the methodology followed targets to overcome. Therefore, this chapter provides:

- the definition of the problem;
- the technological implications and design issues faced in this new area of immersive experiences; and
- the methodological approach adopted by this study to provide solutions to address those challenges.

3.1 Problem definition

360-degree video-based applications can offer highly immersive experiences when turned to applications for VR headsets. The design of such experiences though, becomes challenging due to the 2D video resources used for the creation of interactive experiences in 3D VR worlds as demanded by those devices. It is necessary therefore to form a rigorous design methodology for this new area of immersive experiences. This demands a thorough study of the challenges imposed using 360-degree video in combination with VR headsets and the methods that can lead to the design of immersive and engaging forms of interaction. In addition, use of VR headsets has been correlated with the creation of nausea or motion sickness effects to its users, imposing further implications to this study. As a result, this study focuses on the understanding of the factors that drive those effects which are related to the context of the design of VR applications or the design of the video resources used.

Under the scope to address the need for identifying and evaluating design techniques for the case of 360 video-based immersive solutions, the affordances of that technological medium should be studied. Design guidelines should be also provided to address the problems related to the VR environment and interactive experiences design when targeting VR headset users.

The reasons that make this study complex are:

- the need for designing complex VR environments by integrating 2D/3D assets in 3D scenes where video is displayed in the background;
- the capturing of realistic scenes in 360-degree video that are comfortable for VR headsets and do not cause cyber-sickness;
- the many factors that can affect the overall experience in terms of usability, engagement and immersion;
- the demanding requirements in technological equipment for experimenting with the medium; and
- the lack of a systematic methodological approach for user experience research and interaction design in that area.

In the following sections, we provide a more detailed analysis of the implications and issues that need to be resolved through our methodological approach aiming to address the problem identified in the area of 360-degree immersive video applications design.

3.2 Technological implications and design issues

Our own experimentation with capturing 360-degree video resources and experiencing them using a VR headset, the testing of current solutions available and our preliminary efforts in designing interactive prototypes based on 360-degree video, led to the identification of several implications and pain points that this technology imposes.

The main technological implications rely to the use of the video resources to create a 3D virtual scene that can be experienced through VR headsets. The use of a 2D resource, such as the 360-degree video, to create a VR environment introduces the lack of depth in the scene and therefore limits the user's possibility to navigate freely and explore the world that has been created.

In 360-degree immersive video applications the cybersickness is an additional problem to be dealt with, referring to the feeling of nausea that is created to the user after a few minutes of experiencing immersive applications using a VR headset device. Even the little instabilities in the test video resources that may have been captured; the fast change of view direction; or the height of camera position can make the VR headset users feel dizzy immediately, as they do not control the view and movement of the world they are being placed.

The aforementioned issues imposed by the use of such VR technology have to be considered and resolved when designing 360-video immersive experiences, as they can lead to extremely uncomfortable situations for the users. Currently, when producing 360-degree video resources and using them to create immersive applications dedicated for VR devices it is suggested to the designer to avoid locomotion for comfort though this could limit the level of interaction with the environment. According to a guide for shooting 360 videos by the BBC Academy VR hub (BBC, 2019), acceleration; deceleration; or change of directions too quickly; and much movement in general should be avoided when capturing 360-degree videos. This study attempts to propose ways of overcoming cybersickness effects by experimenting with more comfortable moderate motion design techniques.

The following section provides a more thorough analysis of the list of challenges that the designers face when trying to create more interactive, immersive experiences of 360-degree video for VR devices, due to the implications and design issues identified.

3.3 Research design

In order to address the complexity of this study the research has been carefully designed by specifying a set of systematic methods and procedures that should be followed.

The overall research process of this study evolves through different and discrete stages following a user-centered iterative design approach (Norman & Draper, 1986; Gabbard, et al., 1999). User-centered design refers to a multi-stage procedure where the user is always the focus throughout context and requirements analysis, hypothesis formation, prototypes testing and evaluation.

This research is based on the five stages defined for the design thinking process as proposed by Hasso-Plattner, Institute of Design at Stanford (d.school) (2009; 2010). The five stages in design thinking are: 1) empathize; 2) define; 3) ideate; 4) prototype; and 5) test. This iterative approach as the prototype design and testing can give insights for the re-definition of the empathy outcomes and/or the ideation. Empathy refers to the understanding of the targeted users and their needs while definition deals with the problem specification. The ideation deals with the formation of the main ideas for solving the problem adopting them in the prototyping phase and evaluating them through testing at the end.

Following Plattner’s approach, a slightly moderated methodology with six stages has been formed for the purposes of this study, depicted in the diagram shown at Figure 3. 1.

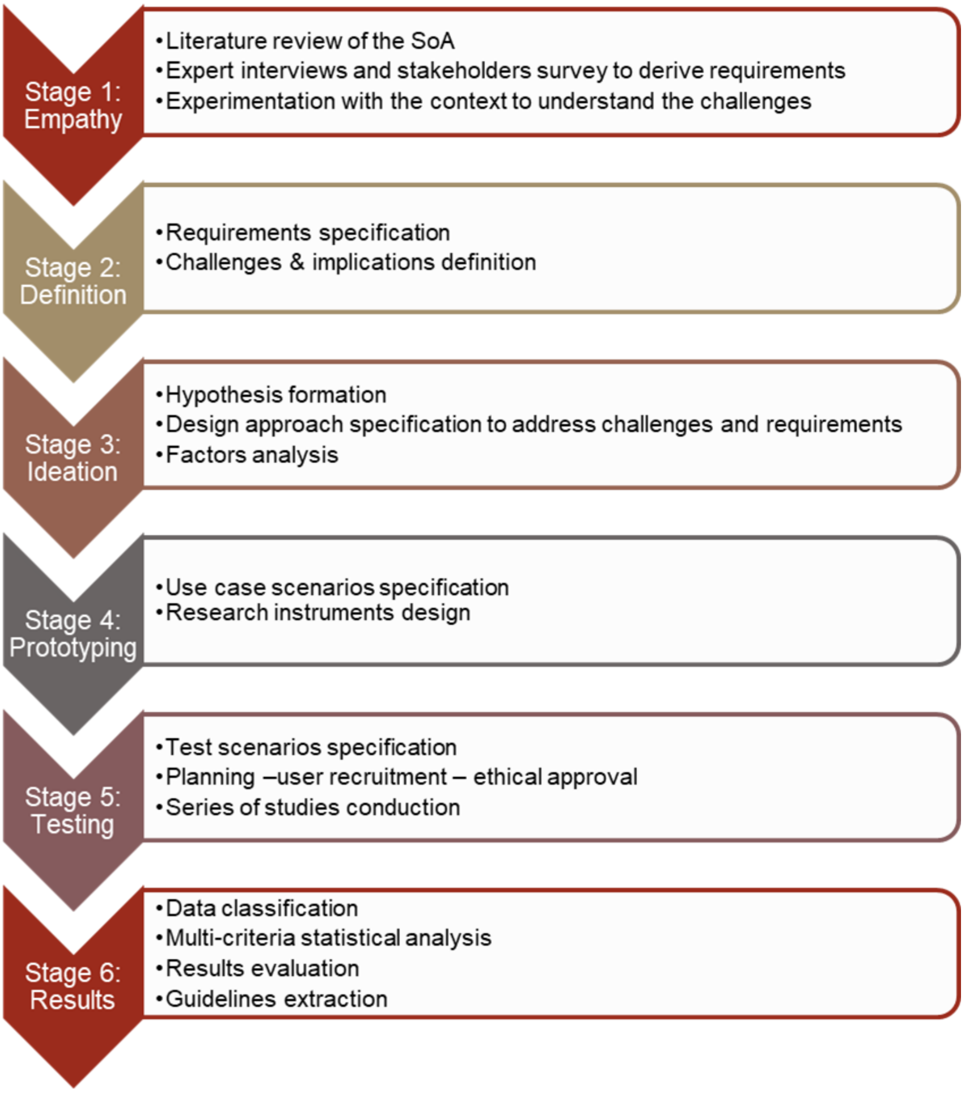

Figure 3. 1: Research design stages

The six stages are the following:

- Stage 1: Empathy

More specifically, the first stage of the research study, the Empathy stage focuses on extensive literature review and state-of-the-art analysis accompanied by empirical research and analysis of data derived from user surveys (face-to-face interviews and focus groups discussions) involving professionals from the field of media production and experts in VR and HCI. A detailed study on the technology of 360-degree video, after experimenting with this medium, has been also been performed leading to the definition of a clear set of technical and design challenges that need to be addressed in that area.

- Stage 2: Definition

The results of the first stage supported the clarification and definition of a list of technical and user requirements depending on the targeted user groups of 360-degree immersive video and led to the design of appropriate functional requirements that is the outcome of Stage 2. That stage involves the definition of a clear list of challenges and implications that should be overcome through the design methodology and guidelines formed as an outcome of this project. As a next step, several factors are listed that can affect usability and the quality of the user experience or can create engagement with the medium and lead to a state of immersion.

- Stage 3: Ideation

This stage deals with hypothesis formation and the definition of approaches, design methods and techniques that could address the challenges identified in Stage 2. As a follow up, a formal design methodology that can be followed in 360-degree immersive video applications has been formed.

- Stage 4: Prototyping

The specification of the context of the research instruments and their development takes place at this stage, transforming the theoretical knowledge into prototype applications. In addition, a concept of architectural design depicting the processes that need to be followed when developing interactive 360-degrre immersive video prototypes was formed.

- Stage 5: Testing

This stage deals with the testing of the prototype applications. Test scenarios have been identified and tools for data collection have been created. A user recruitment procedure was formed. The testing procedure has been designed according to the University of Westminster research ethical policies. The prototype applications were then evaluated in a controlled lab environment through real user testing. The usability testing methodology was also used for the evaluation of the overall Quality of Experience offered, analysing also the results by observing closely the user’s reaction when using the application.

- Stage 6: Results

This stage deals with the classification of the collected data followed by the required statistical analysis that leads to the final results’ interpretation. The interpretation of the results provides valuable recommendations for designing prototype applications of 360-degree immersive video and leads to the formation of design guidelines.

3.4 Methodological approach

This study follows a specific and systematic methodological approach in order to provide solutions and contribute to the design of VR headset applications that are based on 360 videos. Following an analysis of the requirements and challenges in this area of research, it tries to identify the processes that should be followed towards addressing those challenges. It focuses on providing a formal classification of the design considerations and proposed methods that could address those and then formulate an evaluation methodology to assess those techniques and methodological framework. The evaluation methodology, following our iterative design of research in user experience studies, involves prototyping, case studies design, data analysis and interpretation. At the following sections we provide an analysis and justification of our selected methods and research approaches followed in all those phases.

3.4.1 Design process analysis

The next step after the specification of user requirements and challenges in 360-degree immersive video as also the technological affordances is to analyse the design processes that could address those and assist decision making. With design processes we refer to the steps that need to be followed at the ideation phase in order to define the appropriate methods and techniques that should be applied in the creation of a detailed design specification of our prototypes (Ertas & Jones, 1996). That design specification will form as a guide for developing the final products and services.

In design processes analysis we work on defining the necessary procedures that should be followed and the expected outcomes of each process. Significant design processes are the analysis of requirements, the use case scenarios design, the design of interactive tasks etc.

This study tries to analyse all these processes considering the specific needs in the area of 360 video interactive experiences design. The results of the conceptualization of design techniques are used to potentially address the defined user and functional requirements providing a categorization of those at each design process based on their applicability.

During that stage of analysis, the outcomes from the factorial analysis mapping are used to support decision making during the design of 360-degree immersive video experiences.

The results on the methodological approach that is followed for the analysis of the design procedure are further described in Chapter 4 concluding with a presentation of a design framework for the case of 360-degree immersive video experiences creation.

3.4.2 Evaluation methodology

To evaluate the design methods and techniques identified there are several processes that are suggested in user experience studies and user-centred design. Such evaluation processes are usability studies, cognitive walkthroughs, and experimental studies. In usability studies we evaluate the ease of use of a product by letting the users try it and observe their behaviour and actions (Nielsen, 1994).

The cognitive walkthrough assessment technique (Wharton, 1994) refers to a strict and detailed procedure that involves the users in performing specific tasks with the system. It can run at any stage of design, even during wireframes production, but it is highly controlled by the moderator and the test tasks, their sequence and actions performed by the users are predefined.

The aforementioned methods can be extremely useful in defining pain points and assessing findability, ease of use, user satisfaction and effectiveness and efficiency of specific approaches and information architecture followed. They are not enough though neither appropriate for research studies that require thorough multicriterial analysis and considerations of performance measures and several system, environmental, and behavioural factors. This study also tries to evaluate the contribution to more complex user experience factors beyond usability, such as engagement and immersion.

Experimental research and testbed evaluation on the other side, can address these requirements following also an iterative studies approach where the results of each phase drive the next testbeds design. Testbed evaluation can assist the assessment not only of a single technique, but for a combination of design methods followed. Testbeds evaluation is useful for assessing interaction in VR as they provide a representation of different tasks and techniques in various environments and allow the collection of performance data from several parts of the testbed experience. They allow the assessment of combinations of techniques, multiple variables and measurements allowing a more holistic evaluation of performance metrics (Bowman et al., 2001).

Experimental research is examining the cause and effect relationship between variables analysing the effect of independent variables to dependent variables. Correlational research is assessing the correlation between two variables through statistical analysis and observation.

All these methods (experimental and correlational research through testbed evaluation) define the proposed framework of evaluation methodology of this piece of research and are used as a next step of preliminary exploratory investigations performed in the research project's lifecycle. Exploratory studies are trying to explore and provide answers on "why" and "how" by observing users trying out representative prototyping solutions and taking notes under the scope to extract assumptions on the user's behaviour, needs and preferences (Paré & Dubé, 1999).

In order to create the required testbed prototypes aiming to perform a multicriteria evaluation of design methods applied, the results from the previous stage of research were studied. The testbed evaluation design is based on the definition of design subtasks and the categorization of relative techniques and methods. Following that categorization and with the aim to isolate sets of techniques to be assessed we proceed with the specification of a set of case studies and corresponding environments that incorporate different methods. That approach allows for a comparative evaluation of different techniques applied in a set of environmental scenes of a specific case study. The selection of a specific case study allows for the evaluation of the proposed approaches in a simulated real case scenario of 360 video-based experience. The following section provides a justification on the selection of a case study for the testbed experiments of this piece of research.

3.4.3 Case study prototyping

The research and evaluation based on specific case studies is a common qualitative method in information systems science (Darke et al., 1998). Through case study research we are able to empirically investigate the proposed methodological approach within a real case scenario concept and thoroughly analyse its effects under the selected context. It also allows the research to unfold through multi-case studies making feasible the cross-case analysis though different settings of applications (Yin, 2009). Those multiple-case studies could be context compatible and designed under a specific global scenario selected for the overall study allowing the examination of the effectiveness of the techniques in several dimensions.

The multi-case studies approach is compatible also with the aim of this research to isolate sets of techniques and assess their applicability in different environments. The fall of this studies under a chosen application context also makes the studies feasible in terms of available resources, effort and time. Otherwise each testbed evaluation study per each selected combination of techniques and in different settings of application should have been performed, which would be impossible under the project's time frame.

The design of immersive storytelling experiences in the form of virtual educational tours in an area of cultural heritage interest has been chosen as a selected application to serve the needs of this study. Those immersive experiences are based of course on the use of 360 video resources and interaction design techniques. The reason for selecting that application field is the potentials of the usefulness of 360 videos with interactivity in those case scenarios and the possibility to design strong narratives of historical interest while also incorporate gamified design techniques in educational contexts. The cultural heritage artefacts preserved in different locations of a selected area allow their historical interconnection under a storytelling experience. Artefacts serve also as POIs allowing the integration of different mechanisms that assist interaction with the environment and the context and navigation in the virtual scenes.

Therefore, the main case study under which the testbeds have been designed is an interactive virtual tour experience in the streets of the historical centre of the Rethymno city in Crete, Greece. Rethymno is a city of historical interest with many preserved artefacts from the Ottoman and Venetian period hidden in the alleys of its centre.

Two different prototypes have been created to address the needs for experimentations of this piece of research. The prototypes are designed to allow the assessment of different design approaches and combinations of those. The two-phase study approach is based also on the iterative design research to allow assumptions extracted from the first phase to be applied and re-evaluated at the second stage of studies (see Chapter 6 & 7). The large number of techniques and their different application context makes it difficult to design a single study and a testbed that incorporates all in once. We have decided to split those techniques by designing two multi-scene prototypes where each scene follows a different design approach under the same context allowing the comparative evaluation but also the isolated observation of the effects of each approach.

At the diagram in Figure 3. 2 below we provide a visualisation of the evaluation procedure:

Figure 3. 2: Evaluation process diagram

The detailed specification of the design of those two testbed applications and the results derived from each study are described in Chapters 6 and 7 that follow.

3.4.4 Reasoning

In research studies there are three ways of reasoning:

- **Deductive;**
  Deductive reasoning follows a top-down approach in building theories by first defining theoretical assumptions to create the hypotheses and then proceeding with experimental studies and quantitative as also qualitative data analysis (Robson, 2002).
- **Inductive;**
  Instead, inductive reasoning follows a bottom-up approach by first collecting and analysing data from real case studies and then constructing theories based on the researcher’s observations’ interpretation (Quinn Patton, 2002).
- **Abductive;**
  Abductive reasoning is based on iterations in research assumptions build by revising the theory after the results of the experimental studies (Dubois & Gadde, 2002). It allows therefore the modification of theories developed or the creation of new ones based on the

observations derived from the studies. It is a popular approach in design science as it is actually a combination of both deductive and inductive reasoning.

This PhD research follows mainly the abductive reasoning approach provided it addresses the iterative approach adopted by the research design. Initial theoretical assumptions have been constructed that could address the challenges identified, followed by empirical studies involving real users evaluating the developed prototype testbeds that incorporate those assumptions and revising and elaborating the theory through the interpretations of the results from each study.

3.4.5 Methods for data collection

The methodology that best fits the purposes of the proposed study combines both qualitative and quantitative research methods for data collection. Quantitative research applies to the study and analysis of statistical numerical and non-numerical data though objective assessment studies. Qualitative research targets the definition of “why” and “how” dealing with the observation of specific case studies where the assessment is done through direct interviews and the use of structured and un-structured questions.

The methods that have been used to collect data on users’ performance and subjective as also objective evaluation feedback varied in the two different studies based on the purpose and design of the tests. The following list presents the series of methods used at each phase of the studies.

First phase studies:

- interviews
- questionnaires
- log mechanisms

Second phase studies:

- moderator notes
- questionnaires
- log mechanisms

In the first phase studies the participants have been interviewed at the end of the experience interacting with the prototype. Interviews were recorded in audio files that were then transcribed. However, some of the interview questions were pre-defined with the aim to collect qualitative feedback from the users on their acceptance and perceived usability, engagement and immersion from the design methods applied. In general, the interviews were kind of relaxed taking the form of an informal discussion allowing the users to freely comment on their experience and provide suggestions of improvement. Interviews provide subjective measurements and rely strongly on users' personal interpretation and susceptibility.

On the other hand, we should also deal with objective measures in order to have a complete methodological approach in evaluating the design approaches followed. For that reason, we have also used structured questionnaires at each phase of our studies trying to translate subjective feedback into objective measurements through the use of Likert-scaled questions. The questions were formed under the scope to measure usability, engagement, and immersion. Specific questions have been also designed to gather demographic data and data related to users' habits, technology literacy and background.

Objective measurements were also gathered though the integration of dedicated log mechanisms in the prototype's applications aiming to record time on task performance measurements. Those log mechanisms were designed to record the time spent by the user to perform a specific task in different stages of the experiences and store them in a structured way in .csv files available for further statistical analysis.

During the second phase studies notes were recorded by the researcher playing the role of the moderator (Monk, 1993). The moderator was taking notes on the users' behaviour when experiencing specific scenes and interaction mechanisms pointing unexpected actions that could affect the data analysis and interpretation.

3.4.6 Data classification and analysis

To analyse the series of data collected through different methods used we have proceeded with a classification and categorization of those to allow comparative and multicriteria evaluation. In order to come up also with valuable assumptions regarding the effect on users' overall experience, engagement levels and immersion we need to also classify the data according to the factors related to those.

The classification of the data has been achieved mainly using a statistical analysis tool, the SPSS, commonly used in research studies. As a first step, the data were categorized based on their measure’s definition in three different forms: nominal, ordinal and scale. Nominal data were collected through questions of true and false answers or with only two options to choose. Ordinal data were those collected through 1-5 Likert scaled questions while scale data were those collected through the log mechanisms recording time in seconds.

Next the data were split to those referring to information related to demographics, background and habits such as age range, profession and gameplay frequency. Moreover, data collected from the structured questionnaires were categorized according to the factors targeted to evaluate such as usability, engagement, and immersion.

Each dataset is categorized per session for each of the participants. Data related to specific techniques evaluation and applied at different parts of the experience were also classified accordingly as also data referring to specific scenes of the overall experience. Therefore, the data collected form each phase of studies are categorized per:

- Session
- Stage
- Section
- Factor

The session refers to an experiment involving a single participant. The stages are different parts of the study such as before experiencing the prototype, during testing and after the completion of the experience by the user. Each stage now consists of different sections. Sections are divided based on the design approaches followed a combination of techniques applied at specific parts of the immersive experience subjected to user assessment. Usually those sections are related to specific virtual scenes of the experience that are characterised by specific functionality and task assigned to the user or parts of those scenes in case there are different interactive tasks incorporated. Finally, the data is categorized per factors measuring related to usability, engagement or immersion.

Data analysis follows also the classification of the data collected as also the hypotheses formed. As a first step, descriptive analysis of each variable defined is performed to extract assumptions on the normal distribution or not of the data. The definition of the data normality allows the decision on performing further statistical analysis where this is a prerequisite. The means, mediums and standard deviation for each data variable are extracted. Those metrics define the trend of our data as also their spread around the average values. Through proportion and standard deviation metrics it is possible to characterize the statistical significance of the sample size of data.

Comparative analysis methods are also used to investigate and evaluate relationships between variables and extract dependable assumptions for specific user characteristics, combinations of techniques or environmental factors. Hypothesis testing methods are also applied to verify the targeted statements based on their value of statistical significance known as the $p>0,05$ rule.

Finally, a multifactorial analysis approach can provide with necessary results on the effect of each factor (configuration, mechanism, user profile characteristics) on the independent variables such as time of task performance for the effects of interactions between factors on the variables.

The detailed specification of each method used, its preconditions and extracted assumptions from the statistical analysis are provided in sections 5.7 and 6.7 for each phase of the studies.

3.5 Summary

This chapter provided a thorough analysis of the research methodology followed in this study coming from the field of User Experience (UX) research. We started with the definition of the problem that this research aimed to resolve in the area of immersive 360-degree video applications design, followed by an analysis of some technological implications and design issues that this problem imposes.

The overall design of the research has been presented following a user-centered iterative design approach compiled by six steps (Empathy, Definition, Ideation, Prototyping, Testing & Results). This methodology has been defined under the scope to address the complexity of the objectives targeted and based on the design thinking analysis introduced by Hasso-Plattner, Institute of Design at Stanford (d.school) (2009; 2010).

This research work focused on a systematic user-centred design methodological approach whose core element was the rigorous design of user studies for testbed technology evaluation and the collection, analysis, and interpretation of quantitative and qualitative results. A more detailed explanation of the methodological approach followed and the methods selected for the design process analysis, the evaluation procedure, the prototyping, reasoning, data collection processes and results classification analysis are being further described in this chapter in section 3.4. Empath, Definition, and Ideation methodological steps followed in this study and their outcomes are described in Chapter 4. Prototyping, Testing and Results analysis and interpretation stages are outlined in Chapters 5 and 6.

The next chapter provides a detailed description of defining a systematic, formal methodological framework for the 360-degree immersive video design analysis.

Chapter 4

4 Immersive Video Design Framework

This chapter provides an analysis of the design aspects that should be incorporated in 360-degree immersive video applications design. It defines two layers of design, the experiential and the interactive. The factors that should be considered when aiming to provide engaging and immersive experiences are defined. A set of techniques corresponding to each layer is also introduced in the form of a taxonomy of design layer - design aspect - design factors-technique.

The chapter concludes with the presentation of the iVID (Immersive Video Interaction Design) Framework that provides systematic approach for the design procedure, the steps and techniques that should be followed for 360-degree immersive video applications. The iVID framework satisfies the second objective (OBJ2) of this study as defined in Section 1.1.

4.1 Requirements analysis

The first and most important task in a user experience research study is to define the user requirements and the unique characteristics of the targeted users. In this study, the user profiles that have been identified have interest in playing games, experiencing VR and consuming immersive media and their specific needs and requirements need to be analysed.

Generation Z, called also "Web generation" or Post-Millennials, refers to those born after 1990 which are tech-savvy, frequent users of social media, instant messaging applications, mobile web and mobile gaming (Williams, 2015). As a generation keen on multitasking, finding it hard to focus and having high expectations in entertainment and innovative technologies they desire new forms of engaging and immersive experiences (Beall, 2016; Pirker, 2017).

A consumer study in 2015 by Greenlight (Leibach, 2015) revealed that 79% of the Generation Z (are excited to experience VR with millennials (Generation Y - born after 1985) reaching 73%, Generation X (born between 1965-1985) 70%, and baby boomers (born between 1945-1965) 64%. Generation Z is the most passionate therefore for trying out VR experiences with hardcore gamers (playing at least once a week) seeking and looking forward to experience VR gaming (85%). In addition, the study showed that it is not only about gaming, but mostly about interactive entertainment forms demanded by all types of users and all ages with slightly most of them being interested in VR for TV, movies, and video (66%) in comparison to gaming (60%). Therefore, it is expected that this study results will be significant for all those users interested in experiencing interactive 360-degree immersive video solutions, which fall under that category of interactive VR entertainment and video experiences.

User requirements have been defined after a systematic analysis of the literature review followed by surveys through discussions with experts and professionals in the area of 360-degree video, media production and VR research.

During the user requirements’ phase two meetings with professional teams with expertise in the area of interactive and immersive video have been organized in order to identify user requirements for the area of 360-degree immersive video based on the outcomes of their customer research and business needs analysis.

The first focus group was with CTVC (http://www.ctvc.co.uk/) in early 2016, a London based media Production Company focusing on the development of media resources for educational purposes aiming to challenge and inspire. The outcomes of the focus group pointed out the requirement for creating innovative forms of immersive experiences and novel applications in the area of media production by incorporating 360-degree video. The second focus group was the same year with Visualise (https://visualise.com/) professionals, an award-winning VR production studio designing also 360-degree video solutions for VR headsets and the Web, based again in London. Visualise media producers emphasized the necessity for more rich and affective media experiences as also the request of users to interact with the context and control their VR experience in 360 video solutions. The company VR developers pointed out the lack of design guidelines and formal methodological framework for creating immersive interactive solutions that are based on 360-degree videos.

Analysis of the literature led to the extraction of further requirements for this new medium. The need for overcoming nausea effects is a serious consideration in solutions for VR headsets as it affects the sense of comfort and immersion (Kolasinski, 1995). Moreover, focusing on immersive experiences it is important as the user wants to feel as actually being there in the VR world created and feel like interacting with and being part of the experience. Last, the users need to be able to navigate in the 360-degree scene captured and the VR world expecting a more realistic experience. Users also need to be guided around areas of interest as when experiencing the video scene through VR headsets with a field of view covering only the 1/9 of the total captured, they fear that they are missing something important which is out of their view (Zoric et al., 2013; Argyriou et al., 2016).

Below the list of the main user requirements derived are summarised followed by a mapping of those to design requirements using the same coding (User requirement -Ur1- Design requirement- Dr1, Ur2-Dr2, etc.).

User requirements

Ur1. Experience novel applications - innovative form of VR interactive apps;

Ur2. Be able to interact with the context and the environment and control the experience;

Ur3. Be able to move inside the VR world without feeling nausea or motion sickness;

Ur4. Be immersed - feel part of the environment;

Ur5. Experience rich and affective stories;

Ur6. Be guided in the VR world;

Ur7. Be motivated and focused – engage with the experience.

Design requirements

Dr1. Create new forms of immersive interactive applications with the use of 360-degree video;

Dr2. Create a mixed media 3D interactive environment with a UI design for VR headsets;

Dr3. Integrate smooth moderate motion techniques;

Dr4. Effective use of mechanisms and design approaches so as to not break immersion;

Dr5. Design strong immersive storytelling experiences;

Dr6. Integrate effective and efficient navigation mechanisms;

Dr7. Effectively gamify the VR experience.

That list of design requirements is addressed in our study through the definition of a formal methodological design framework for 360-degree immersive video solutions whose stages and processes are further described in the following sections. The next section provides an analysis of the key challenges identified under the aim to address the 7 design requirements specified.

4.2 Challenges in designing 360-degree interactive video applications

There are several challenges and implications that must be addressed when trying to create immersive, interactive and engaging experiences with the use of 360-degree videos. In this section we discuss two kinds of challenges, those that deal with technical implementations and those that refer to the overall design process (Argyriou et al., 2016).

These are based on the limitations inflicted by the video itself which is used as the main game scene and lacks depth of virtual space where the user can navigate. In conventional virtual environments the user can navigate in complex 3D geometries reconstructing real spaces, attempting to simulate reality, or creating imaginative spaces that cannot exist in real life. Moreover, another sensitive issue that makes the design of interactions more complicated in 360-degree video applications is the sense of presence that the user should experience. The user's sense of presence can be enhanced by creating a natural and close to real environment and by avoiding incongruous visual cues allowing in this way smooth interaction in the virtual space.

Our approach in addressing those challenges is to focus on designing strong, realistic, rich and cognitively demanding interactive narratives with the use of 360-degree video following a systematic methodological framework. A list of technical and design challenges is presented below, that withdraw from our study and aims.

4.2.1 Technical challenges

Technical challenges refer to implementation and development considerations that arouse when trying to create interactive and immersive experiences with 360 videos for VR headsets. At the definition stage of this research three key technical challenges have been identified in the effort to address the user and functional requirements derived at the previous stage. Those are presented as follows:

TCh1. Smooth transition between video resources;

In order to address Ur5 and Dr5 requirements (as defined in section 4.1), requires the creation of interesting narratives and the design of immersive interactive applications that are not disruptive. By using 360 videos to design such a storytelling experience, one of the challenges to be addressed is possible delays and blinking effects when changing between the video resources that are used as the subplots of the storyline. The transition between the video resources should be smooth and seamless in order to ensure an unbroken and consistent presentation of the story. The users should be able to focus only on the story and the facts presented and feel like they are being part of it. Therefore, any kind of meaningless interruption and distraction that can break the feeling of immersion must be avoided.

TCh2. Natural, close to real environment;

Focusing on addressing Ur4 and Dr4 requirements (see section 4.1) which refer to the sense of presence in a VE, natural and realistic scenes should be provided. Besides the capturing and use of 360-degree video that is a real representation of the world, 3D objects can be also included in the environment in order to allow interaction with the content. As the background scene is created through the projection of a video source, the appearance of 3D objects incorporated in it should be as realistic as possible presenting a consistent and natural environment. For this reason, the reconstruction and rendering of the objects should be first of all relevant to the video captured scene while representing a real model of the world.

TCh3. Reality-based navigation;

The request of reality-based navigation relates to Ur3 and Dr3 requirements (see section 4.1). Navigation in video applications is mainly time-based using the forward, or backward options to move between the frames, or based on the camera movement support for pan, tilt and zoom (Petry & Huber, 2015). The goal of interaction designers should be to allow the user to perform tasks naturally, to provide additional non real-world functionality, and to use analogies for these commands whenever possible (Jacob et al., 2007). In order for the users to feel that they are actually part of the story, they actively participate, navigate and interact in it, the scene should mimic the real world.

4.2.2 Design challenges

Design challenges relate to the overall design issues and UX considerations of 360-degree immersive video interactive experiences, such as UI design considerations, navigation design problems and gamified mechanisms applicability. Below, those design challenges are described as another output of the ideation stage of this research:

DCh1. Non-intrusive, non-distractive user interface design;

> The design of the graphical user interface in such experiences should be as transparent and non-intrusive as possible giving the sense of an augmented view of the real scene with the minimum info required for running and controlling such experiences. Moreover, the interaction with the UI such as the use of menu and the display of any informative text should not pause the game scene and make it vanish from the player's view as this comes in contrast with our aim of offering immersive experiences. This challenge is related to Ur2, Ur4, Ur7 and Dr2, Dr4, Dr7 requirements (see Section 4.1).

DCh2. Navigation and orientation mechanisms;

> The need for guidance in the VR scene requests for efficient navigation and orientation mechanisms (Ur6 and Dr6, see section 4.1). Another important design challenge, therefore, is the support of navigation and orientation in 360-degree video, as in panoramic view, parts of the video the user should see and interact with, could be out of the user's sight. As the users can freely navigate in the panoramic view, they may easily feel anxious they are missing something important (Zoric et al., 2013). In such rich environments consisted by 360-degree video, new navigation mechanisms should be designed and integrated to help user orientation in panoramic view while reducing the cognitive load.

DCh3. Gamified design;

> Finally, an important aspect for addressing the request of providing engaging experiences (Ur7) is the gamification of the experience (Dr7) (see Section 4.1). Adopting design techniques from games can lead to creating a more engaging and motivating experiences. There are various game mechanics and gamification

techniques that can be integrated to the design of interactive applications in order to offer more fun and engaging experiences (Gamification elements, 2016). The challenge that must be addressed in this study is to invent an effective combination of the right game mechanics that can be adopted to the design of 360-degree interactive video applications without diminishing the user's feeling of immersion.

4.3 Guided design

As discussed in the previous section, there are many challenges that need to be considered and addressed in the new area of 360-degree immersive video design. The design of immersive and interactive applications for VR headset consumer experiences based on 360 videos requires different approaches and methodologies to the ones applied in VR CGI worlds and VR games. Therefore, there is a need to provide solutions on the methodological design approach that should be followed in order to address the specific user and technical requirements for this new technology.

Recent studies provided some significant results towards the direction of extracting design guidelines for interactive omnidirectional videos (iODVs) production (Saarinen et al., 2017). The term "Interactive omnidirectional videos" - iODVs introduced by Kallioniemi et al. (2017) refers to the integration of interactive content in ODVs and UI elements. Design guidelines are essential recommendations for UX designers and immersive applications developers targeting to offer experiences that attract their audience. They provide ways of design and targeted recommendations to application designers guiding them to address specific UX challenges.

Currently, there is no holistic approach on a methodological process that should be followed in: incorporating game design techniques; integrating appropriate UI elements; providing navigation assistance; and designing the narrative production in order to address interactivity and design for immersion and engagement issues in 360-degree immersive video.

This study follows a systematic approach by analysing how design thinking should evolve in the area of 360-degree immersive video, how it should be applied during application development and concluding with the derivation of a set of design guidelines that should be followed in order to create engaging 360-degree immersive video experiences. The systematic methodological approach introduced by this work is described in the following sections.

4.4 Experience and Interaction design formal analysis

Interaction design is "*the practice of designing interactive digital products, environments, systems, and services.*" as defined by Cooper et al. (2007) and focuses mainly on studying the users' requirements on interacting with a specific medium and analysing their behaviour. User experience (UX) design is an extension of HCI focusing on improving the usability, desirability and accessibility of a solution, service, or product. It is the practice of design with the aim to increase the quality of the user experience (Hassenzahl, 2013). This project focuses on the formal specification of the experience and interaction design process as a methodology for the design, categorization, and incorporation of a combination of techniques that can lead to immersive and engaging 360-degree video experiences.

Aiming to address the usability and interaction issues imposed by the use of 360-degree video resources in building immersive applications that target VR headsets users; a systematic design analysis process is formed. The proposed methodology starts with the investigation, analysis and categorization of experience and interaction tasks that need to be addressed in the design of 360-degree video based immersive applications to offer engaging and immersive experiences. As a follow up, we proceed with defining a formal taxonomy of experience and interaction techniques that could address the identified tasks targeting to increase the user's sense of immersion and engagement. This formal design taxonomy is inspired by Bowman & Hodges (1999) work for Immersive Virtual Environments (IVEs) and adapted for the case of 360-degree immersive video applications. Figure 4. 1 illustrates the taxonomy format of Bowman & Hodges (1999) that break down each design task in sub-tasks and technique component.

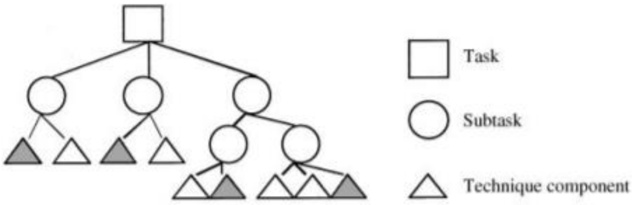

Figure 4. 1: General taxonomy format of design techniques by Bowman D. & Hodges L., 1999

Categorization which refers to the classification of design techniques within the framework of a taxonomy assists the verification of taxonomies defined and their generality (Bowman & Hodges (1999). Techniques addressing a specific design task/aspect that fit well into the taxonomy defined provide insights for its correctness and completeness. The evaluation process of techniques identified and proposed is aided by the categorization process. Fundamental differences of design techniques are more obvious when a taxonomy has been defined also making their selection and application more concrete, clear and systematic. The design analysis approach that this study followed for the specification of a methodological framework in depicted in Figure 4. 2.

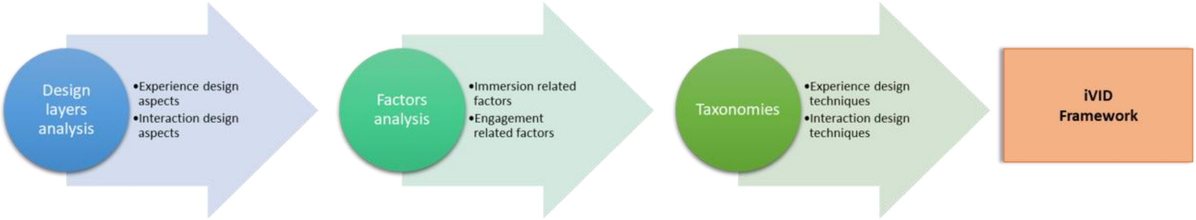

Figure 4. 2: iVID framework specification procedure

Its starts with the design layers and corresponding design aspects analysis, the analysis of design factors for engagement and immersion and the provision of taxonomies of techniques corresponding to each layer. The methodological approach developed based on the design analysis outcomes is presented through the definition of a design framework, the iVID framework. The iVID framework is a step-by-step guide for designing engaging and immersive experiences that are based on 360-degree video resources. The iVID framework is presented in detail in Section 4.9.

4.5 Immersive Video Design Layers

As a first step of the design analysis conducted in this study, the design of 360-degree immersive video experiences has been divided in two layers:

- **the experience design layer**, that covers all aspects that support the experience design, such as the narrative design, the design of the virtual scenes and the design of roles for the captured human actors in the video scenes;
- **the interaction design layer**, a significant part of the design process, complementary to the experience design layer, that deals with tasks related to navigation in the virtual world,

interaction and system feedback through UI design, as well as the integration of gamified aspects to increase engagement.

Those two different layers of design and their aspects mapping is depicted in Figure 4. 3. Each layer presents different requirements, challenges and guidelines that need to be followed.

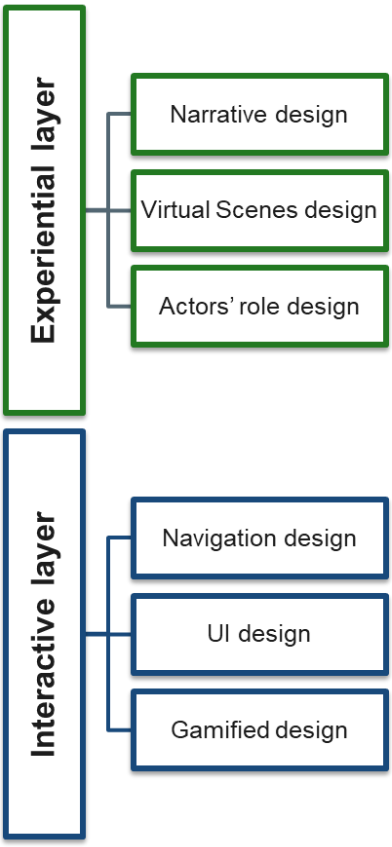

Figure 4. 3: Layers of design in 360-degree video applications

An explanation of the design aspects defined for each layer is provided as follows:

Experiential layer

- **Narrative design**;
  includes the specification of how the story unfolds, the overall story design, and techniques that should be followed to increase engagement and immersion in 360-degree video storytelling experiences. Narrative design is a key aspect in the creation of immersive experiences promising for enhancing the engagement level of the users (see

Section 2.7). Research and analysis of efficient techniques and methodologies for narrative design has been also introduced for the area of immersive journalism experiences based on 360-degree video by Hardee (2016) pointing out the importance of methodologically addressing this aspect. Well-designed, interactive narrative can support the goal of presence as stated by Hardee (2016).

- **Virtual scenes design**;
  refers to the definition of elements that should be captured or integrated in the scenes to support the storytelling experience. The position of the scene elements is critical as parts of the video displayed in the background will be hidden that could be important for the story context understanding. Those elements are also important for the interactive tasks design. A dynamic visualiser for 360-degree video annotations handling and a framework for the scene building process has been introduced by Matos et al. (2018) justifying the necessity for careful and imperative scene design and interaction elements positioning.
- **Actors' role design;**
  involves the scripting of the actions of humans captured in the video scenes. Human actors efficiently directed during the video capturing process, could provide an element of social engagement supporting users to immerse in the story or even used to guide the user's view direction. The importance of virtual actors in VR immersive application has been also justified in Section 2.9. Further to that, Keskinen et al. (2019) have experimented by assessing the effect of actors positioning (away or near the camera) and behaviour (moving around) to the 360-degree video viewers experiences concluding that distance should be kept to more than one meter. Further research is required though on the effect of specific actor actions to the viewer's experience in more interactive contexts.

Interactive layer

- **Navigation design**;
  is an important interaction design task for assisting viewpoint reference and scene-to-scene transition (see Section 2.10.2). How the user would move from one scene to another so to progress in the story and explore the virtual world created should be carefully designed avoiding cybersickness. Preliminary experimentation with different scene transition techniques for immersive 360-degree video experiences has been performed by Moghadam & Ragan (2017) assessing how those can influence spatial orientation, sickness, and sense of viewers presence. The techniques proposed

(teleportation, animated interpolation, and pulsed interpolation) caused disorientation and made it difficult to track scene changes. The Animated Interpolation technique (smooth viewpoint motion from scene-to-scene) proved to be best for addressing sickness and spatial orientation. More comprehensive studies on addressing scene transition are though suggested.

- **UI design;**
  is necessary to support the interaction with the VE and give feedback to the users. Traditional 2D-screen UI design techniques used in VR and games are not applicable for VR headsets. The field of view and the way the user experiences the VE and interacts with it is vastly different in a 360-degree canvas. UI elements design and positioning for immersive games for HMDs can influence the player's experience (Babu, 2012). It is considered crucial therefore to analyse design approaches for the task of UI design in 360-degree immersive video applications and provide guidelines for their application so as to be non-intrusive and non-distractive (DCh1 – Section 4.2.2). Saarinen et al. (2017) have also researched UI elements design and positioning for guiding the users of ODVs.
- **Gamified design;**
  refers to the design of interactive tasks that incorporate game elements and techniques in the experience to enhance the user's engagement with the medium (see Section 2.8). Gamified scenarios and interaction techniques should be defined focusing on introducing missions that could be supported efficiently in 360-degree immersive video experiences. Downes et al. (2012) have introduced 360-PlayLearn a platform of technologies such as gamification and Game-Based Learning (GBL) for interactive TV video applications dynamic creation. Such aspects should be considered also in applications dealing with immersive video forms.

In the following section an analysis of factors related to immersion and engagement is provided. Those factors should be considered when aiming to define techniques appropriate for each of the defined design aspects in the area of immersive applications design.

4.6 Factor analysis for immersion & engagement

In order to be able to identify efficient techniques for each of the six design aspects of 360-degree immersive video experiences, the design factors that are significant for creating immersive and engaging experiences should be studied first.

VR experiences are effective when the user is in a state of flow in which readers are both immersed and engaged (Douglas, & Hargadon, 2000). The sense of immersion and engagement could be achieved through the consideration of a set of selected factors derived from the literature as depicted in the following diagram based on previous studies in VR design. Figure 4. 4 below lists a set of factors that are considered relevant also to 360-degree immersive video experiences.

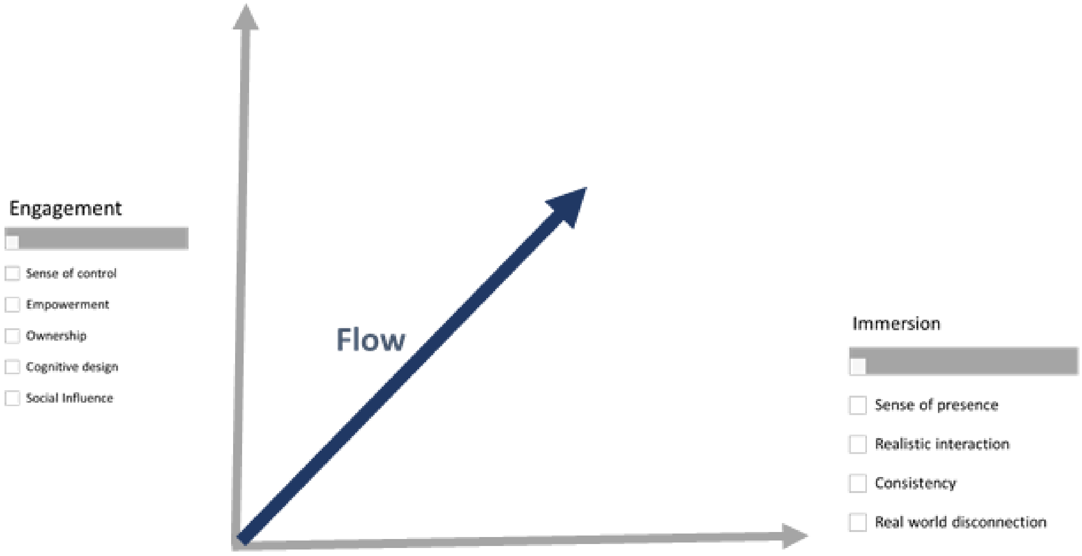

Figure 4. 4: User's flow state through engagement and immersion

Table 4. 1 provides a mapping of the design factors related with the senses of immersion and engagement to corresponding design aspects for each of the two layers of 360-degree immersive video experiences. This formal categorization of the factors assists the definition of design techniques that could address the designed aspects in order to create engaging and immersive 360-degree video experiences. The factors mapping per design aspects has been formed considering their applicability in each case meaning that design techniques addressing the specific aspect are possible to support such factors.

		Design aspects per layer					
		Experiential			Interactive		
Design factors		Narrative	Virtual scenes	Actor's role	Navigation	UI	Gamified
Design for engagement	Sense of control	●			●	●	●
	Empowerment				●	●	●
	Ownership	●				●	●
	Cognitive design	●		●			●
	Social influence	●		●			
Design for immersion	Sense of presence		●	●			
	Realistic interaction			●	●		
	Consistency	●	●			●	
	Real world disconnection	●	●	●			

Table 4. 1: Mapping of engagement and immersion design factors to design aspects of 360 video-based experiences

Design for engagement

Sense of control: In order to achieve the sense of engagement, users should have a sense of control over their experience as this stimulates the feeling of enjoyment (Csikszentmihalyi, 1992). Control relates to the feeling of confidence the user has of knowing the effort that needs to be spent for a task completion and finds the experience easy and clear to use (Rozendaal et al., 2009). Sense of control should be taken into consideration at the narrative, navigation, UI and gamified aspects design to integrate design techniques that will give the users the necessary tools to control their experience.

In Octalysis gamification framework (Chou, 2013), that is a formal approach for successful gamified and engaging applications design and evaluation, some of the core design factors defined are social influence, empowerment, and ownership. Those factors are considered also important based on their definition for the creation of engaging experiences that are gamified in the area of immersive applications.

Empowerment: The sense of empowerment and the provision of feedback refers to the involvement of users in challenging activities and should drive the gamified design task, navigation, and UI design. A fun and rewarding experience design, empowers users and can lead to high levels of usability and user engagement (Nielsen, 2003).

Ownership: is also a factor related to the interaction with the environment and provision of personalised experiences and is therefore related with gamified design, UI design and narrative design. The feeling of positive affect is related to emotions triggered by the interaction offered. "*Engaged users are affectively involved*" (O'Brien & Toms, 2008). Affective experiences can be very motivating creating the desire to the user to explore further the environment they are in and make the experience personal (Jennings, 2000).

Cognitive design: A significant aspect towards engaging the users is the cognitive design that is related to strong and thought-stimulating experiences and should be considered in narrative, actor's role, and gamified design. Storey et al. (1999) have proposed and hierarchy of cognitive issues to be considered during the design of a software exploration tool and how cognitive design elements could be applied for an effective interface design. Directional and arbitrary navigation and orientation cues provision are among the elements studied.

Social influence: is a factor that refers to the importance of social feedback and should be considered for the narrative and the actor's role design where the involvement of humans in motivating the users can play an important role towards engaging them. The presence of virtual humans can affect the user's performance in accomplishing an interaction task in a VEs (Hoyt et al. 2003) and therefore such design approaches should be experimented also in the context of new immersive forms of experiences.

Design for immersion

Besides the consideration of methods that promise to drive engagement, the design analysis should focus on creating the sense of immersion in 360-degree video experiences under the scope of leading the user to the state of flow.

Sense of presence: In order to produce immersive experiences, the design process should aim to create the sense of presence to the user by designing and capturing rich, affective and realistic experiences for the narrative design, the virtual scenes and actor’s role design (Slater, 1999).

Realistic interaction: The provision of realistic forms of interaction is also an important factor that should be considered in the navigation and actor’s role design. More natural, realistic forms of interaction can increase the sense of users’ presence making them feel as actually participating in the experience (Wall et al., 2014).

Consistency: The design should be also driven by consistency, meaning that the UI elements should make sense in the environment and the environment should respond to the user actions (McMahan, 2013). Therefore, the techniques selected for the UI, the virtual scenes and navigation design should be driven by consistency.

Real world disconnection: The design of the experience for all the tasks corresponding to the experiential layer should be focusing on disconnecting the users from the real world and immersing them in the virtual experience. In order to be fully immersed in the experience the user should exclude the interaction with other people and elements of the environment that are not involved in the current task he/she must accomplish and focus its attention. This is something related to distortions in the subjective perception of time when the user interacts with the VE (O’Brien & Toms, 2008; O’Brien et al., 2010). The lack of the sense of time is an indicator of immersion and cognitive involvement (Baldauf et al., 2009). When the user is concentrated to the experience, feeling absorbed and losing the sense of time, leads to the sense of flow, having an optimal experience of being fully focused and immersed (Csikszentmihalyi, 1990).

At the following sections, a taxonomy of design techniques that could address the defined tasks at the experiential and the interactive layer is provided. The taxonomy is based on the analysis of the design aspects and provides a decision-making framework for the selection of each technique by a designer according to the requirements of the application scenario (Bowman & Hodges, 1999).

4.7 Taxonomy of experiential design techniques

In order to define the taxonomy of design techniques for the experiential layer of 360-video immersive experiences appropriate techniques should be identified that correspond to each design aspect and are related to the corresponding factors (see Table 4. 1). By analysing the design aspects while taking into consideration the experience factors in VR, described at Section 4.6, a list of techniques for 360-degree immersive video applications design has been defined.

The taxonomy of the design techniques that we have defined for the experiential layer, after a thorough design analysis, is shown at Figure 4. 5 below. This taxonomy is structured as design layer-design aspect-design technique-factors.

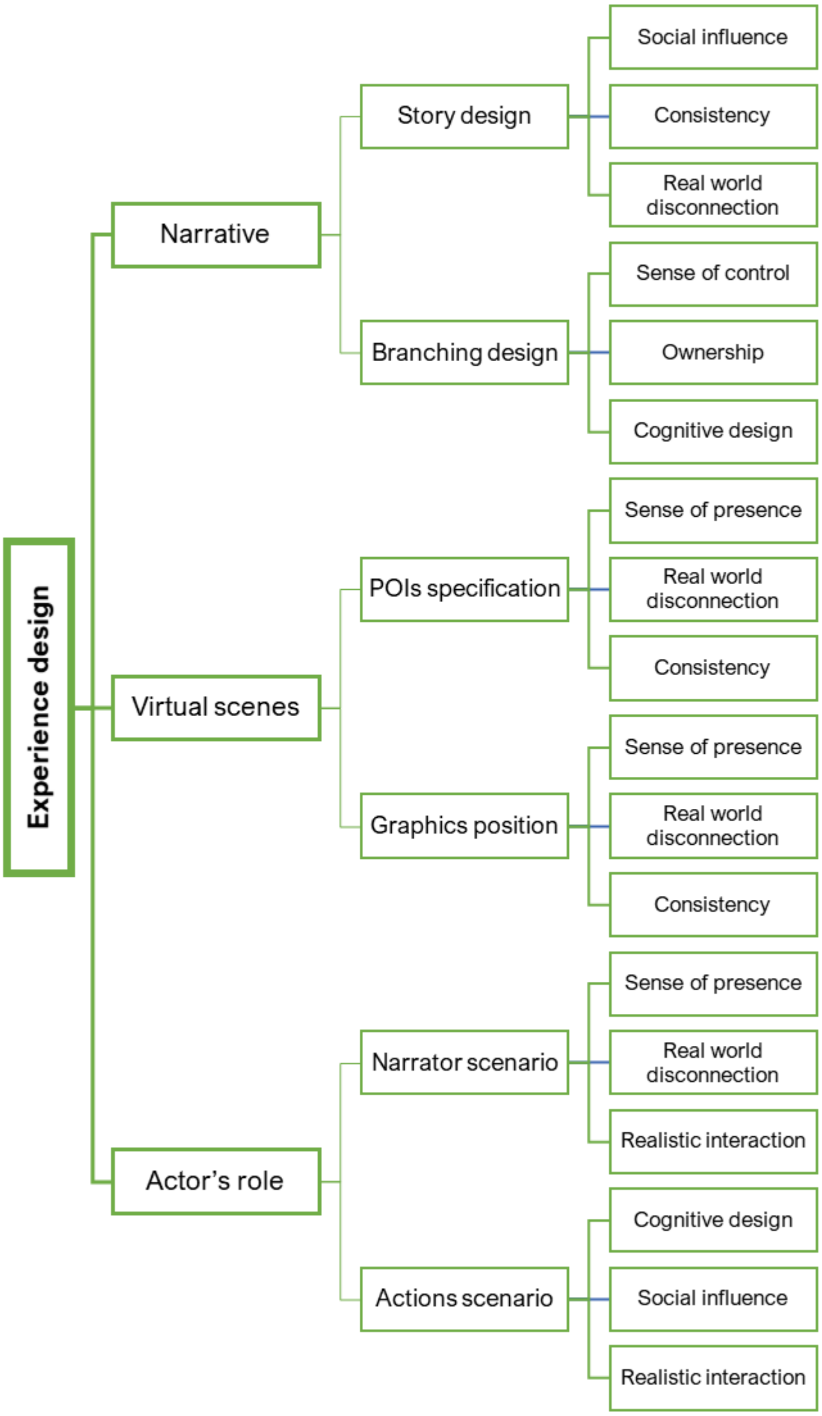

Figure 4. 5: Taxonomy of experiential design techniques

Narrative design

The first design aspect is the narrative design, referring to the specification of how the story unfolds. To provide social influence, consistency and real-world disconnection, strong and interesting stories that engage the user and create empathy should be designed. This categorization of factors to specific design techniques and aspects assists the appropriate selection of methods to be applied and processes to be followed in the overall video production specification and content creation phase. The design of the story and the production scenario should focus on the representation of a real-life scenario that has a specific application context such as the virtual tour in an outdoor archaeological area or in a university campus and the elements of the story should be consistent and support interaction through social influence.

To increase the sense of control, provide cognitive tasks and give the sense of ownership to users, the technique that should be adapted in narrative design is branching storytelling (Louchart & Aylett, 2005). In branching storytelling different paths of scenes that could be visited are defined allowing users to choose their preferred path to experience a story/narrative. To achieve branching storytelling the story design should be adapted to follow a non-linear design specification which should be used during the videos production and editing phase. This categorization and factors consideration mapping can assist the specification of processes that should be followed when defining the script for branching storytelling design scenarios.

Virtual scenes design

Virtual scenes design refers to the definition of elements that should be captured or integrated in the scenes to support the storytelling experience. With the aim to design for consistency and create the sense of presence and real-world disconnection, the scenes should depict areas and points of interest (POIs) that are contextually related in a storytelling experience. Those POIs could be for example historical buildings in a virtual city tour experience. Graphic elements such as text panels should also be integrated in each scene to provide further information about the POIs. The POIs and graphics positioning specification per scene allows the strategic design of each virtual scene and the definition of the user's viewshed and available interaction tasks when entering each scene.

Actor's role design

Actors' role design involves the scripting of the actions of humans captured in the video scenes. Human actors efficiently integrated in the scene, taking the role of narrator, could provide better sense of presence, real-world disconnection, and realistic interaction. Realistic interaction can also be provided by human actors used to motivate the user look around, creating also social influence and cognition. The human's actions and narrative specification should be produced and used during the videos production and editing process.

To conclude, each technique defined at the experiential layer should be followed according to the scenario and purpose of the experience; depending on how we want our users to feel. To assist the application of defined processes derived based on the experiential layer aspects/techniques/factors categorization, a set of design guidelines is proposed though this work as an outcome of testbed evaluation (Bowman et al., 2001) (see sections 5.7 & 6.7).

4.8 Taxonomy of interaction design techniques

Following the analysis of user requirements (see Section 4.1) that pointed out the necessity of interacting with the context of 360-degree video applications and being able to control the experience, the definition of techniques for the interaction design layer is required. The process of interaction design specification should focus on the set of challenges specified (see Section 4.2) for providing navigation support (DCh2) and comfortable UI elements (DCh1) in 360 video-based experiences.

The taxonomy of proposed techniques for the interaction design layer follows the same structure and serves similar purposes of use as the experiential layer and is presented in Figure 4. 6.

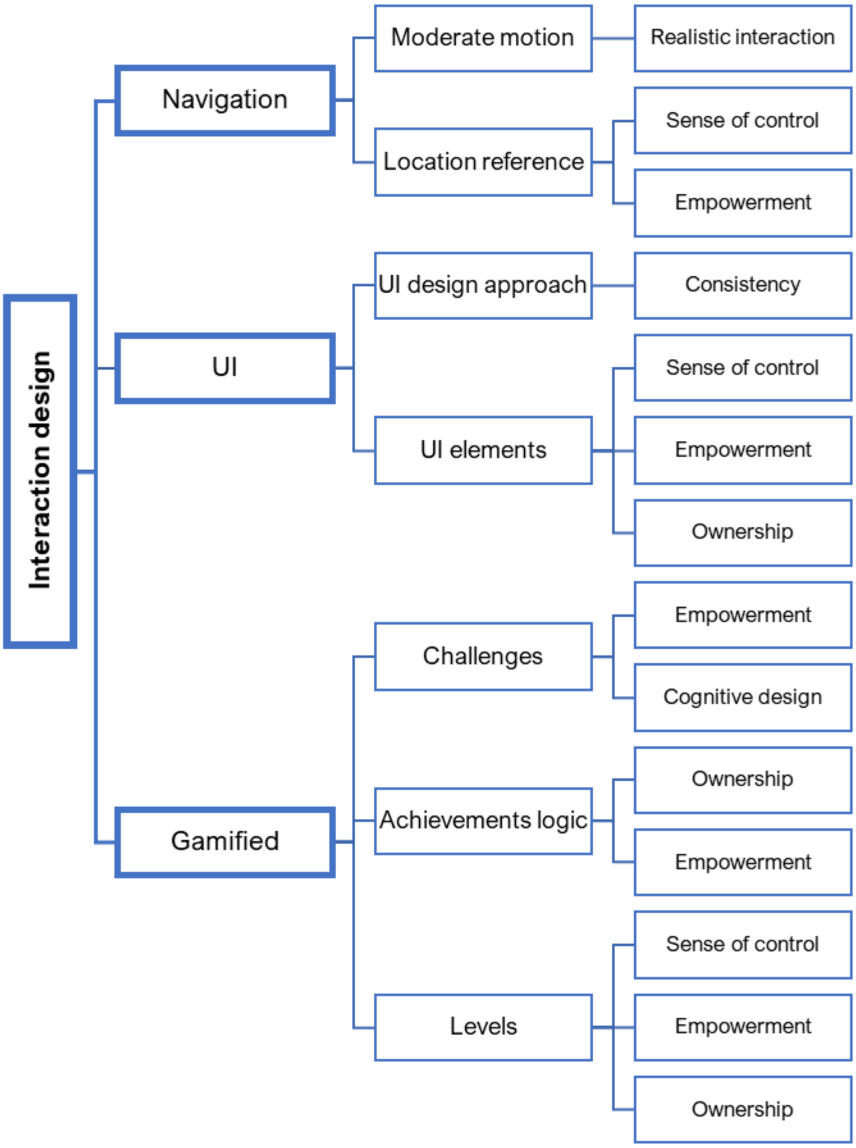

Figure 4. 6: Taxonomy of interaction design techniques

Navigation Design

Navigation design is an important interaction design aspect in assisting viewpoint reference and scene-to-scene transition. Moderate motion is a technique that refers to user navigation in a multi-scenery environment and progressing in the story. To achieve a more realistic interaction with the 360-degree immersive environment and the effect of “feeling like being actually there in the virtual world” (Slater & Usoh, 1993), walking video resources could be produced and integrated in the experience. 360-degree videos with locomotion should be carefully produced if intended to be experienced though HMDs. Fast camera motion in 360-degree videos has been reported by Tran et al. (2017) to produce strong sickness effects when used in VR communication. 360-degree videos that are captured through steady and slow walking in an area could be used for VR world navigation, simulating a real walking experience to transition from one scene to another. This technique can provide realistic interaction with the VE. Another moderate motion technique to navigate the virtual world is the direct teleportation that could give a sense of controlling better the scene-to-scene transition and empower the user. Location reference techniques should also be considered providing the user with feedback of where the POIs are placed in the scene according to her current view, leading to the empowerment and control.

UI Design

One of the most important aspects in interaction design is the design of the user interface that allows the display of system information to the users about their actions and its elements convey interactivity. For the users to be able to get feedback on their virtual experience and interact with the environment it is important to provide effective UI elements. As pointed out in the design challenges earlier (see section 4.2.2), the UI design in the case of 360-degree video-based experiences should be non-intrusive and non-distractive. Moreover, the design targets experiences for VR headsets the most promising technique that can be applied is the diegetic UI design (User Interfaces for VR, Unity, 2018). The diegetic UI design approach could be an efficient way of providing a more realistic interaction and maintain consistency in the environment as the elements appear as 3D objects placed somewhere in the virtual scene. Placing and scaling the UI elements should also be defined carefully as they could clip important areas or elements in the scene or be too far to be legible. Another technique for UI design that could be applicable in the case of 360-degree immersive video is the non-diegetic. Non-diegetic UI elements are attached to the camera and remain always visible to the user. Therefore, the non-diegetic design could give a sense of control and ownership to the user. Attention should be paid though when selecting that technique as the UI could be obscuring to what the users should observe in the scene hiding important parts of the experience. The selected UI design approach should be consistent to the VE while the UI elements integrated should provide the user with a sense of control and ownership and create feelings related to empowerment.

Gamified Design

Gamified design is an efficient technique for the creation of engaging experiences. In cultural applications educating users on historical, cultural, or even environmental facts is a typical requirement. Such tasks to be engaging and effective should challenge users' thinking, motivate them to dive deeper in the story, explore its affordances and assess their capabilities. Efficient design techniques for creating such experiences come from the area of game design. The design of challenges following a cognitive approach is allowing exploration and discovery by gradually revealing information to the users about observed POIs while navigating different scenes and by assessing their knowledge. Addressing challenges creates the send of empowerment to the user. Achievements technique has to do with increasing the sense of ownership and empowerment, which can be achieved when the story unfolds in a way that allows users to achieve specific goals. Empowerment and ownership can also be achieved by allowing users to level up providing a sense of control and increasing their motivation. The design of an experience with levels could be achieved by exploring scenes and POIs gradually and providing in-formation and feedback as the story progresses.

Based on the described analysis, the main interaction design considerations have been classified also forming a taxonomy of the interaction design techniques. The taxonomies defined for each layer of design in 360-degree immersive experiences are part of the overall methodological design approach presented by this study in the form of iVID framework that is analysed in the following section.

4.9 The iVID Framework

The iVID (Immersive Video Interaction Design) Framework is the outcome of the methodological design analysis presented in this study for the case of 360-degree immersive video (see Figure 4. 2). This framework provides a formal specification of the design procedure, the steps and the design methods that should be followed in 360-degree immersive video experiences.

"*Patterns, components, and interaction design frameworks have a different scope in the design of applications. Whereas a design pattern provides a solution to a recurring problem, an interaction design framework is a set of design patterns enhanced with other elements and information, used in combination so as to guide the design of a complete system or context.*

Interaction design frameworks are at a high level of abstraction and are a guide for helping designers choose which patterns to use….”—Robert Hoekman, Jr., and Jared Spool (2010).

Instead of supplying therefore a narrow solution to a narrow problem, frameworks handle more complex problems. Interaction design frameworks offer guidelines for the design of whole contexts in a structured and clear approach.

The diagram of the iVID framework can been studied at Figure 4. 7 below, depicting the design process flow, the design stages and the taxonomies that should be taken into consideration so as to be able to extract and apply a set of effective and efficient design techniques in the lifecycle of the design of 360-degree video based applications that are immersive and engaging. The iVID framework provides a systematic methodology for the design analysis assisting the definition and selection of design techniques promising for addressing the challenges identified in 360-degree immersive video applications development.

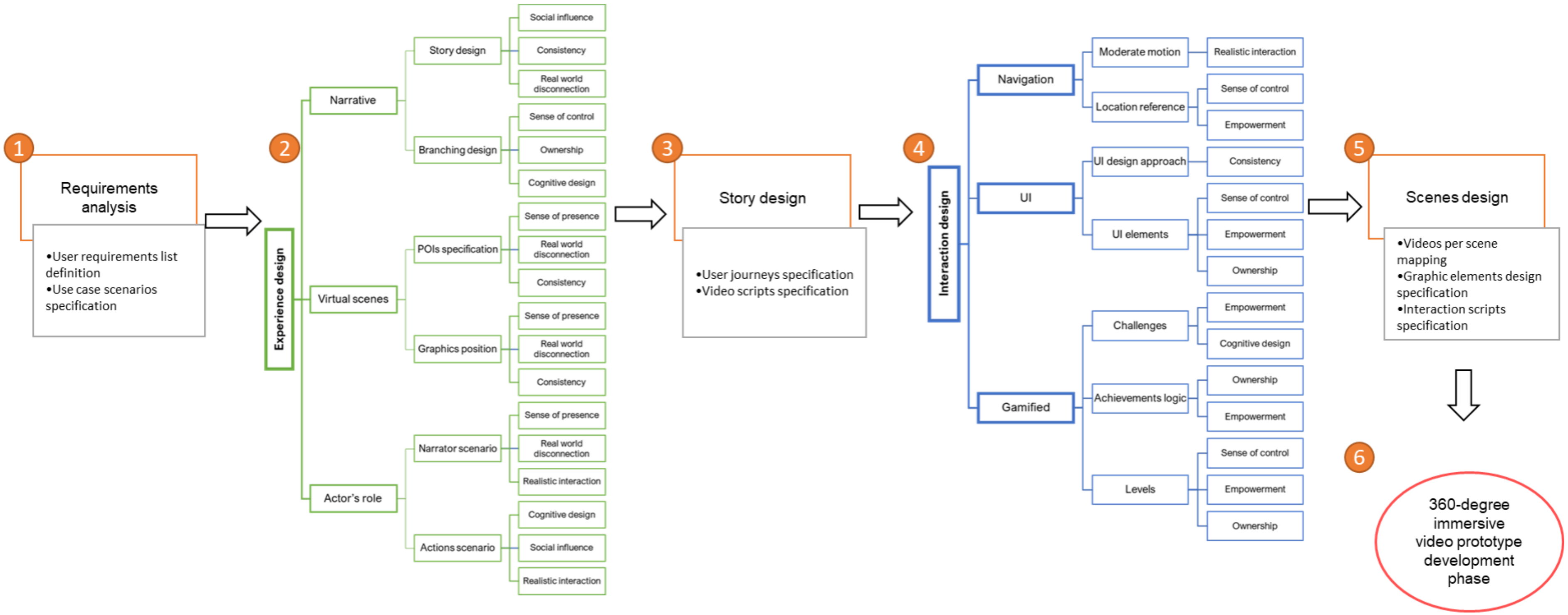

Figure 4. 7: The iVID framework

The iVID framework consists of six design stages:

Stage 1: Requirements analysis
Stage 2: Experience design
Stage 3: Story design
Stage 4: Interaction design
Stage 5: Scenes design
Stage 6: Prototype development

Each of these stages relies on the outcomes and specifications of the previous stage.

4.9.1 Stage 1 - Requirements analysis

The design process starts with the analysis of the application requirements. At that stage, a list of requirements of the targeted users in terms of desired functionality and performance should be defined. The scenarios the application should serve need to be also specified following the requirements specification. Those definitions will assist the selection of the appropriate design techniques at the next stage. A general list of design requirements is provided in section 4.1. According to the scenario of the application we would like to build, some of those requirements should be considered essential and need to be further specified. It is up to the designer to decide the application scenario and purpose (edutainment, educational, just for fun, immersive storytelling for empathy, etc.) and elaborate on corresponding requirements selected. For example, in the case of a virtual tour CH storytelling application design further targeted design requirements should be specified that should guide the definition of appropriate methods and design elements to be applied. In case the purpose is to be able to guide the viewer in a scene with multiple points of interest that they should observe at they own pace Dr6 should be of a first priority and sub-requirements should be defined such as: integrate intuitive navigation mechanisms for user guidance in a 360-degrees one-direction rotation cycle for multiple POIs discovery with no time limit.

4.9.2 Stage 2 - Experience design

The stage of experience design starts with the analysis of the requirements and the scenario definition. Based this analysis, the selection of the most appropriate techniques for each design aspect of the taxonomy follows, according to the scenarios and the desired functionality targeted. The techniques for the narrative design, the virtual scenes and the actor's role design are defined following the taxonomic categorization. The defined techniques can be related to a set of factors such as the sense of presence, provision of realistic interaction, design for consistency and achieving real world disconnection that promise to lead to immersion; and also the sense of control, empowerment, ownership, cognitive design and social influence that can increase the sense of engagement to the user. The design techniques should be selected based on the specific requirements defined and scenario of the application and the targeted factors. This process assists the definition of methods aiming to address some of the challenges identified TCh1, TCh2, DCh2 (see sections 4.2.1 & 4.2.2).

Narrative design

To offer the user the expected feeling of immersion and sense of actively participating in the story, an interesting narrative that unfolds through 360-degree videos should be designed. Good stories attract the user to the experience, while make the world seem more realistic and believable. In 360-degree immersive video narrative experiences design, one of the challenges to be addressed is the creation of a smooth transition between different video resources (TCh1). For narrative design, according to the iVID taxonomy, the story flows the application should support should be designed so as to maintain consistency, create real-world disconnection and even support social influence in the virtual experience. Therefore, methods selected to be applied should not break the sense of user's in participating in the experiences ensuring an unbroken and consistent presentation of the story without interruptions or meaningless actions and events. Methods should be defined for the scripting of the story and the video production design to support a real-life application scenario.

Branching design can also be considered applied through methods and processes that can efficiently support cognition, action control and sense of ownership by providing for example the option to the users to select their own path to the story. Branching storytelling is promising for offering the user an enhanced sense of presence as it creates the feeling of control and active participation in the scenario. Several 360-degree videos should be captured in order provide enough content to allow the story to unfold according to the user selections/decisions. Branching storytelling was used for the creation of the narrative experience offered in the first prototype (see section 5.2). Methods to support branching storytelling have been applied in the design of the first prototype (see section 5.3.2) and subjected to user evaluation.

Moreover, when designing 360-degree video narratives in a game engine, screen fade-in and fade-out techniques between video resources can be enabled and disabled respectively to avoid the blinking effects when transitioning between scenes. To avoid delays when transitioning on-the-fly from one video resource to another, different spherical objects can be used, where each video resource is already associated as a movie texture asset. Disable and enable techniques can be used when moving from one scene to another to ensure smooth transition. For example, the videos should have been already preloaded and be in pause state in order to avoid delays during play time when dynamically loading videos in the device's memory. This requires a carefully story design and video scenes specification form the beginning as also careful editing of the resources captured to support the application of such transitioning effects.

These methods for addressing smooth transition (TCh1) have been applied in the design of the research instruments of the first (Chapter 5) and second phase (Chapter 6) studies of this project and subjected to evaluation.

Virtual scenes design

In the phase of virtual scenes design, the definition of POIs that should be captured or integrated and annotated during the experience should be considered. Graphics positioning methods should also be defined in a way that address TCh2 while supporting real-world disconnection, consistency with the VE and maintaining the sense of presence.

POIs should be specified at this stage to be adequate with the story and methods for their capturing process should be defined as also annotation techniques through graphic elements that are non-intrusive and non-distractive. For enabling interaction with the scene and the content of interactive 360-video applications, graphical elements can be integrated in scenes to allow users to interact with them and change their status. A series of 2D/3D objects could be placed in the inside each 3D spherical scene (where the video resource is mapped) associated with the relative video resource of the narrative. The 3D objects become visible to the user by making use of game's scene lights and placing the objects according to the lighting source of the real scene that has been video captured (sunlight source, building light sources etc.). In this way, a realistic lighting and shading of the 3D objects in the scene can be targeted.

Following the aforementioned steps, leads to the creation of a virtual reality environment that combines video content and computer-generated 3D/2D graphic elements. As a result, another challenge needs to be addressed, that of making the environment more natural and closer to real (TCh2). Attention should be given though to use 3D objects that match the videos projected and the context of the story and position them in the scene so as not hide important areas depicted in the video background scene. The position and transformation of the objects in the scene should be adequate to the captured video scene. In case for example that the video shows the user to move to a specific direction of the captured area, the scale of the 3D objects placed in the scene could fluctuate in perspective according to the user's view. For the first instance of the second prototype, 3D objects representing ancient vases have been integrated and carefully positioned in the different scenes and scenes have been designed following the specification of POIs that should have been captured and annotated to support the virtual tour scenario purposes (see section 6.2).

Actor's role design

A key challenge when creating storytelling experiences in 360-degree free view-point video is to try to direct the viewer at specific points of the scene and at specific time frames (DCh2). A promising method for directing the user's attention is the use of human actors performing in a way that motivates the viewer to change its view direction. An interesting technique towards triggering the viewer's curiosity to look towards the direction that the main story takes part, is to capture another person starring for a few minutes at this direction. Like in real world we stimulate the sense of curiosity making the viewer thinking that something important is taking part at that part of the scene worth to experience. A more realistic and effective approach could be the engaging of the viewer and the increase of the feeling of presence by starting the whole experience depicting a person looking at the viewer, talking to him/her, and then turning to the direction where the main story takes part. Eye contact creates a connection of the viewer with the human captured in the 360-degree world in a very profound way. The viewer will probably turn to that direction also feeling curious of what is happening there. In VR experiences the user can be usually influenced but not controlled or forced to look where the content creator wants them to look. The viewer is the storyteller by deciding how to explore the content.

Human actors can also be used to support the realistic aspect of the storytelling experience by performing the role of the story narrator. Methods for capturing human actors to serve as narrators in an engaging and realistic way should be defined. Specification of the movements and speech that they should perform should be provided at this stage considering the provision of an engaging and immersive storytelling experience supporting real-world disconnection. Their positioning in the captured scene and the capturing process should also be designed carefully supporting sense of presence.

4.9.3 Stage 3 - Story design

As a next step, the story of the experience targeted should be specified. This refers to the detailed design specification of the user journeys and the production of the necessary video scripts. The user journey design is driven by the selected techniques at the previous stage, for example the use of methods for human acting or branching storytelling technique selected to be applied. In the same way, the production design of the required videos is based on the POIs specification or the inclusion of a narrator human figure. During the video scripts specification procedure, the areas and POIs to be captured need to be defined as also the human acting scenarios that should be performed and captured, and their corresponding role scripts.

360-degree video content production can be a very challenging and time and effort costly task. In order to create a short film in 360-degrees, but in high quality four up to sixteen camera devices may need to be rigged and used along with machinery to assist the smooth movement of the camera equipment when filming with locomotion.

In contrast, when recording 360-degree video content using hand-held low-cost cameras with no stabilization assist shaking effects must be avoided. Shaking video content can lead to serious effects of dizziness and motion sickness when experiencing 360-degree video in VR using devices such a Samsung Gear VR or a Google Cardboard. As a first guideline, the content production should be made with as less harsh movement as possible, avoiding elevation changes and quick rotation transforms. For smooth 360-degree video viewing, the captured content should be processed using algorithms for stabilization. Such an algorithm has been recently introduced by J.Kopf (2016), a Facebook engineer. It is a hybrid 3D-2D algorithm for stabilizing 360-degree video using a deformable rotation motion model. This method provides more accuracy, robustness, smoothing ability, and speed than either pure 2D or pure 3D methods, presenting a fundamental building block to the 360-degree video processing pipeline. Specific production methods should be also specified at this stage.

The visitor of such VR worlds based on 360-degree video is experiencing a journey as depicted in the diagram in Figure 4. 8 below. The storyline is not linear as in traditional 2D video storytelling experiences instead it unfolds in circles. Each circle represents a different 360-degree video resource or else a new VR scene. The black and white dots depict the POIs the user can identify according to its current selected field-of view.

As the story unfolds in circles in the case of 360-degree video, the content creators have to design the production of resources by defining POIs that need to be captured in the scene and that could trigger some kind of interaction or the transition to the next scene in the story (or sets of different POIs in the case of branching narrative followed). iVID points out the importance of careful and systematic story design though user journey specification and scripts writing before proceeding to the development phase.

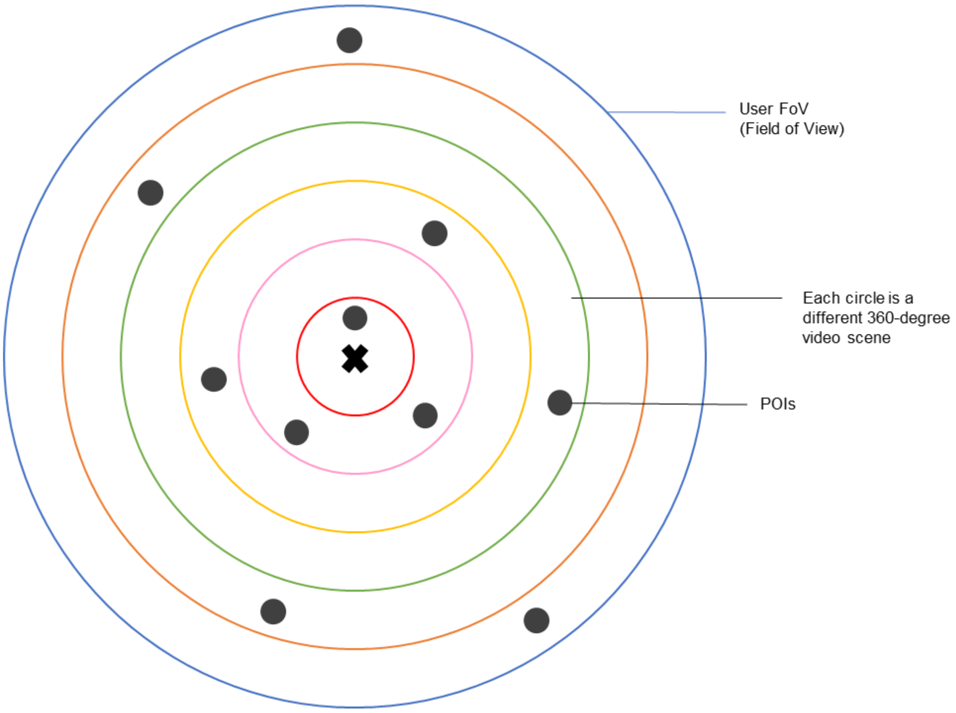

Figure 4. 8: Immersive video user journey - 360-degree virtual worlds' visualization with POIs

4.9.4 Stage 4 - Interaction design

The interaction design stage is also based on the defined taxonomy of techniques per interaction design aspect. Depending on the requirements of the story that unfolds throughout the experience the most appropriate interaction techniques should be selected that can effectively address navigation design, UI and gamified design while supporting the related factors.

Navigation design

In order to increase the user's feeling of presence, TCh3 that refers to designing reality-based user navigation in the environment must be addressed. In 360-video based immersive applications we can design an effect of virtual navigation in the video scene through the capturing and use of video resources in first person 360-degree view, at the average height of the targeted user, where the person is moving in the real world. This is the walking simulation technique as presented at experiential layer design analysis (see section 4.7) and applied in the prototypes design for both studies (see Chapter 5 & 6). Walking simulation effect can be achieved by playing a new video resource where the user is shown to walk towards another area in the real world. In this way, the user has the sense of moving in the virtual scene through predefined paths that have been video captured. Methods and processes for directing and capturing walking simulation immersive videos should be defined supporting realistic interaction and a smooth experience. Directions for avoiding sickness effects though stable locomotion of the camera and the videographer should also be defined.

Location reference should also be supported through the definition of efficient design methods to be applied and supportive graphic elements incorporation (such a pointing vectors).

UI design

The graphical user interface must be carefully designed to be transparent and non-intrusive (DCh1) giving the sense of an augmented view of the real scene. When designing user interfaces for VR applications targeting devices such as the Oculus or the Gear VR by

Samsung, there are several considerations that need to be considered as the screen display is different from the traditional 2D approach. In non-VR applications the UI is non-diegetic targeting HMDs, which means that the UI is not actually part of the world, but it is simply overlaid on the user's screen. When we integrate the UI within the VR environment, a Diegetic UI design approach is followed. In such cases the UI needs to be placed at an easy to read position and scaled accordingly. UI elements in the virtual scene should be placed in such a way that do not obscure objects and content in the scene that the user could interact with. Another common technique is to attach the UI to the camera (non-diegetic approach), placing it at a fixed position as the user moves, but this can lead to effects of nausea and user discomfort. Diegetic and non-diegetic UI design approaches have been applied in the second phase studies prototypes design and subjected to comparative studies (see section 6.2).

In order to address the need of designing a UI that is non-intrusive and non-distractive (DCh1) the controls can be limited to a simplistic Graphical User Interface (GUI) design, depicting only the necessary information required for the player to navigate and interact with the content in the scene. The GUI could consist therefore of digital elements integrated dynamically in the scene according to the scenario of application. Those elements could be:

- a mini map displaying the user's field-of-view and the 3D objects position in the 360-degree environment;

- a pop-up text panel element displaying a question and three possible answers that the user can select, and which appears when a 3D object is selected;

- a graphical display of the time left to address a challenge;

- a graphical element displaying the user's score and level;

- informative image/text panels etc.

Those elements must be placed in the scene to not hide the main viewport or pause the action while they are used mainly to display information without making the VR environment disappear. The mini map GUI element can be a mechanism that could address also the second design challenge for integrating a suitable for 360-degree video applications navigation and orientation mechanism. The users of the second prototype are presented with a 2D "radar" mini map element that continuously displays their viewport, as also the relative position of the 3D objects of interest in the scene in order to assist users to navigate towards them (see Section 6.3.1).

Gamified design

Gamified design can be applied to motivate the users to interact with the virtual experiences and engage them with the context of the storytelling experience. Game elements integration to support user engagement should be considered and well-specified in the design analysis phase (see section 2.8.3). To achieve this, the method selected for the first prototype introduces a mission to accomplish to its users and quests to address in the form of multiple answer questions (see section 5.2). The second phase studies' prototype has also been designed as a gamified experience by introducing tasks to the users of identifying 3D objects placed in different locations of the 360-degree scenes or spot specific elements in the video background (see section 6.2). Time pressure is another game element used imposing time limit that corresponds to the length of the loaded 360-degree video resources. The users are presented with a specific challenge they must complete before the end of the current video play. Limiting the amount of time people must complete specific tasks can impact users focus on addressing the challenges presented. This concept of the specific time or period in which learners intensify their cognitive skills in order to achieve their goals has been referred to as reclaiming the learning time and creating the necessary conditions for the achieving the "learning momentum" (Bouki & Economou, 2015). Time limit for accomplishing specific tasks has been applied in the first instance of the second prototype (see Section 6.2).

4.9.5 Stage 5 - Scene design

The next step is the design of the application scenes. This starts with the use of videos produced during the story design stage and the mapping of those per scene defined. The interconnection of the scenes follows the story specification, the experience design techniques selected, and the user journeys defined at the previous stages. Corresponding graphic elements required to be designed should be specified in detail following the approaches selected and their needs for UI design, gamified design, and navigation at the interaction design stage. To also support the defined interactivity the necessary programming scripts the logic should be also specified per scene and per design element (interaction with scene objects and UI elements and expected system feedback).

4.9.6 Stage 6 - Prototype development

Under the scope to specify the processes that should be followed for creating 360 video-based interactive solutions, a conceptual architecture design has been defined. The architectural design concept is based on the use of the iVID framework outcomes produced at its five previous stages of design thinking, categorization, and analysis. The architecture diagram, as shown in Figure 4. 9 below, depicts the two main processes of the development stage:

- the content production procedural steps (Figure 4. 9A), and;
- the development and integration process (Figure 4. 9B)

for delivering interactive immersive 360-degree video prototypes. Those are explained in the subsequent sections:

A) <u>Video content production</u>

The first phase of development (Figure 4. 9A) refers to the video content production. This phase starts with the study of the design techniques selected and methods specified for addressing the experiential layer design aspects (iVID Stage 2 and Figure 4. 9A1), the user journey specification (Figure 4. 9A2) and the video scripts produced during the story design process (iVID Stage 3) of the iVID framework (Figure 4. 9A3). As a next step, the study results are followed to proceed with the real production of the videos using the necessary 360-degree video recording equipment (Figure 4. 9A4). After all the required video resources have been collected, comes the editing phase (Figure 4. 9A5) that involves stitching, cutting unnecessary shots and working on the categorization and annotation of videos following the application scenarios.

B) <u>Prototype development and integration</u>

Following the video production is the phase of the prototype development and integration that splits in two parts: a) the 360-degree scenes creation; and b) the gameplay and interaction design (Figure 4. 9B). The main core of the development process is the use of tools that allow the creation of 3D scenes and 360-degree immersive video applications for VR headsets (HMDs), the manipulation of VR cameras and the integration of 3D objects and coding of interactive functionality. Those application design and development processes for creating such complex immersive experiences targeting HMDs are facilitated best using 3D game engine tools available in the market.

There are several video mapping techniques suggested to create 3D VR scenes for 360-degree video play that mainly affect the video quality and file size (important for media streaming). The spherical layout has been selected for the prototypes development that facilitated the design of spherical virtual scenes and the better handling of creating complex VR scenes by integrating 3D and 2D elements. Unity 3D engine has been used for the development of the prototypes targeting VR headset devices. Unity 3D allows the creation of interactive 360-degree video experiences and playback of the videos using the Skybox Panoramic Shader when using a spherical layout. The support of equirectangular and cube map layout had been just announced on the Unity blog beginning of 2018 (Unity Blog, 2018).

The scenes creation process starts with the study of the prototype scenes design specification and more specifically with the videos per scene mapping specification provided at Stage 5 of the iVID (Figure 4. 9B1) to proceed with the spherical mapping of the corresponding 360-degree videos per scene (Figure 4. 9B2). The next step (Figure 4. 9B3) deals with the study of the graphic elements specification (following the scenes specification – outcome of the iVID Stage 5 scene design process) which is followed for the design or collection of the necessary 3D objects and their import in Unity as assets available for the corresponding scenes (Figure 4. 9B4). According to the techniques selected and methods defined at iVID Stage 4 for the challenges design, UI design and navigation design of the interactive layer, the required UI graphic elements and action/instruction panels are also imported as assets of the relative scenes (Figure 4. 9B5). UI elements are necessary for the display of notifications and system feedback to the users, the provision of level/ points/badges visualizations and the navigation support view. The final step of this stage is the integration of all the 3D objects and 2D elements in respective scenes and their placement in the 3D spherical space according to their functionality and their relationship with the background video scene (Figure 4. 9B6).

Moving on with the development procedure, follows the coding of the necessary functionality for providing user interaction with the 3D objects and UI elements of each scene and expected system feedback to user actions (Figure 4. 9B9). Those scripts are created following the gameplay and interaction logic that has been defined during the scene design task of the Stage 5 of iVID framework (Figure 4. 9B8) along with the specification of the selected interaction techniques (Stage 4 of iVID) (Figure 4. 9B7) and videos per scene mapping (Figure 4. 9B1).

The last process is the final build of the application exported in the relative formats according to the targeted VR headset or mobile devices that can be used along with VR headsets. Before starting the implementation of the immersive application, the required Software Development Kits (SDKs for building VR mobile applications must be integrated in the development engine. In case low cost Google cardboard viewer devices are targeted for example, the Google cardboard VR SDK (2016) should be loaded in the Unity 3D game engine. For Oculus VR headset devices, the necessary SDKs are already integrated in Unity.

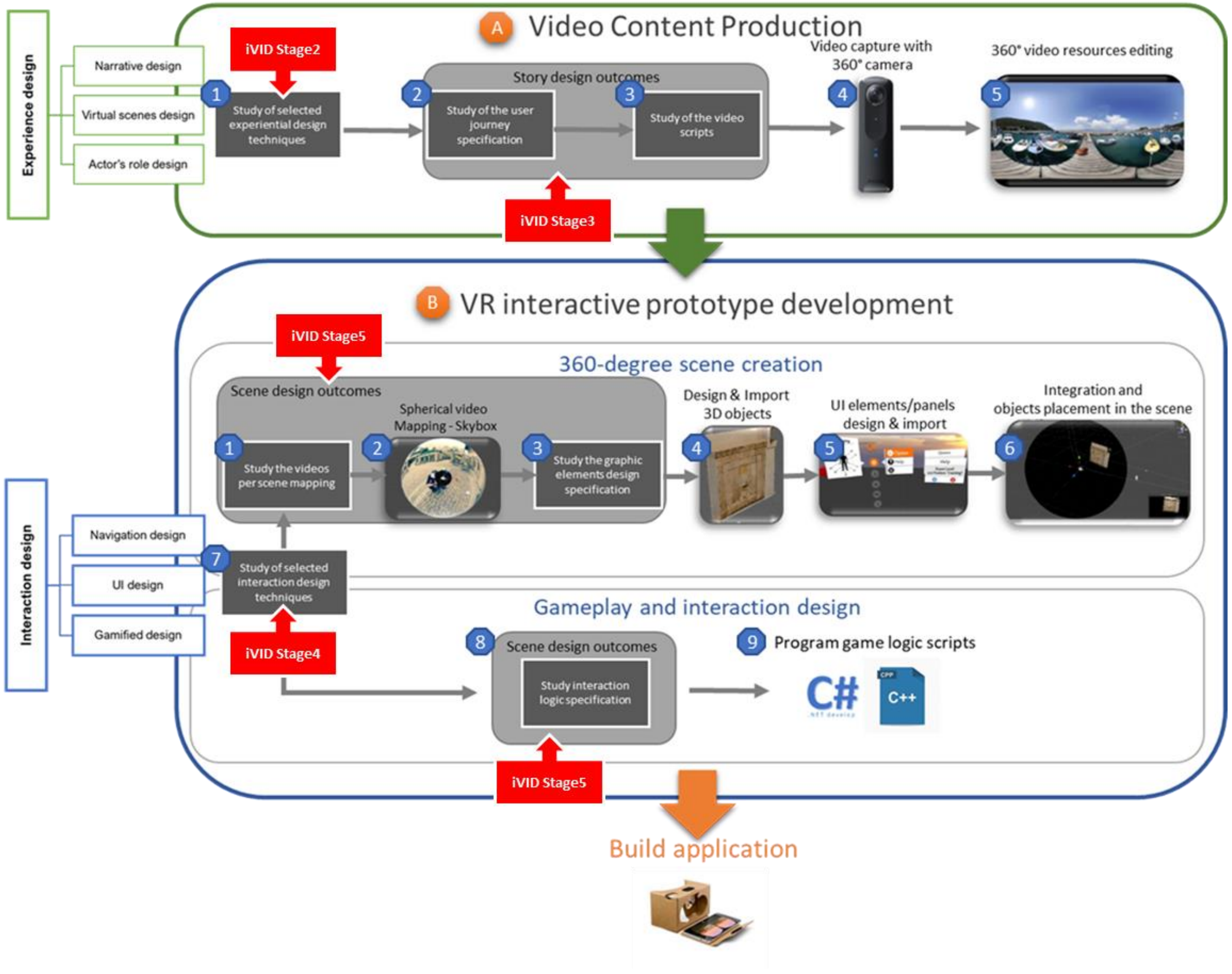

Figure 4. 9: 360-degree video experiences development architecture

4.11 Summary

This chapter provided a description of the design analysis followed in this study and its main outcomes. This methodological analysis addressed the third objective of this project (see Section 1.1) by presenting the iVID framework for 360-degree immersive video. The iVID framework serves as a methodological step-by-step guide for the design thinking process that should be followed when designing immersive and engaging 360-degree video experiences.

The process for defining this 6-stage framework is based on the definition also of taxonomies for the experiential and interactive design layer that follow the structure: design layer-design aspect-design technique-factors. That 6-step design approach defined by the iVID framework provides a systematic methodology for designing 360-degree immersive video experiences for VR headsets though the definition of the necessary design stages and their expected outcomes including formal taxonomies of appropriate design techniques for the experiential and the interaction layers of design.

Several design methods and techniques are outlined base on the iVID methodological approach, as promising ways to address the challenges defined for the area of 360-video interactive experiences. Those methods defined though the iVID methodology have been applied to the design of two different 360-degree immersive video prototypes used for experimental studies involving real users. Real user studies can provide the necessary results in evaluating the specified design approaches for addressing the identified list of challenges. The outcomes of those studies lead to the definition of specific design guidelines that should be followed when applying each proposed technique at the experiential or the interactive layer of the iVID framework. The following two sections provide a detailed presentation of the studies and an analysis and interpretation of their results.

Chapter 5

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5 First phase studies

Based on the scope of this PhD research, the evaluation studies were designed in order to address the following combination of research questions and hypotheses that have been formed following the theories developed about the contribution of design methods to usability, engagement, immersion and user experience. The hypotheses are structured to assess the relationship between two variables or factors of the experiment (such as method – usability). RQ – Research Question, H – Hypothesis.

- RQ01: Is there a difference in **usability** of 360-degree immersive video experiences due to the *design method* applied?
  H01: There is no difference in **usability** 360-degree immersive video experiences due to the *design method* applied.

- RQ02: Is there a difference in the levels of user's **engagement** with 360-degree immersive video experiences due to the *design method* applied?

H02: There is no difference in the levels of user's **engagement** with 360-degree immersive video experiences due to the *design method* applied.

- RQ03: Is there a difference in the levels of user's **immersion** in 360-degree immersive video experiences due to the *design method* applied?
  H03: There is no difference in the levels of user's **immersion** in 360-degree immersive video experiences due to the *design method* applied.

- RQ04: Is there a difference on the effect of the *design method* on the **user experience** in 360-degree immersive video based on their unique profile characteristics?
  H04: There is no difference on the effect of the *design method* on the **user experience** in 360-degree immersive video based on their unique profile characteristics.

- RQ05: Is there a difference on the effect of the *design method* on the **user experience** in 360-degree immersive video based on the application context?
  H05: There is no difference on the effect of the *design method* on the **user experience** in 360-degree immersive video based on the application context.

These hypothesis satisfactions, representing multiple criteria that are being considered, are being assessed through statistical analysis of the collected data from the two phases user studies for each of the methods followed during the design of the testbed stages. Targeted questionnaires have been designed and used during the evaluation focusing on assessing those hypothesis (see Appendix I.1 & II.2).

Chapter 5 provides a detailed description of the first phase studies. The chapter starts by outlining the scope and main objectives of the study. It continues with the presentation and justification of the design methodology that has been followed for the design and development of the 360-degree immersive video prototype that has been used in this study. This design methodology has been defined following the iVID framework steps that assist with the process of defining a set of methods and processes promising to lead to the creation of immersive and engaging experiences. The methods and processes and are subjected to testbed evaluation in the first phase studies concluding with the extraction of a set of design guidelines. This chapter presents the experimental setting and continuous with the presentation of the data output of the first phase studies. Next, the analysis of the quantitative and qualitative data derived from the study tools and methods used. The chapter closes with the analysis of the data drawing conclusion that lead to the formation of a set of design guidelines for the design of effective 360-degree immersive video experiences.

5.1 Aims of the study

In order to be able to provide assumptions and evaluate the effectiveness and applicability of the proposed methodological design approach in the iVID framework (see section 4.9) and its formal taxonomies specified (see section 4.7 & 4.8), a set of studies has been planned into two phases. The first phase studies involved real users testing a 360-video based application for VR headsets, where selected methods and processes has been applied using iVID, providing feedback on their sense of immersion, engagement and usability aiming to reject/accept the hypothesis defined. That first prototype application forms the main research instrument as a testbed that integrates a series of promising design techniques, imposing them to user research experimentation and data analysis.

For the design of the prototype the integration of different techniques consisting the experience has been considered in each scene of the application. Those techniques fall under the experiential and interactive design layers of the iVID methodological framework (see sections 4.7 and 4.8). The methodological design that has been followed for the research instrument is based on the iVID framework for the specification of methods and processes integrated in each stage of the experience and the isolation of several mechanisms so as to be able to extract valid results and avoid the issue of having to create several applications and run multiple tests (this is detailed in section 5.2 and is more clearly depicted in Table 5. 1).

This case study investigates the effect of different design techniques defined using iVID and integrated in a 360-degree immersive video prototype with respect to immersion and engagement levels achieved. The main objectives of this study were:

- the evaluation of the overall design approach followed in terms of engagement and immersion offered;
- the comparative assessment of the effectiveness of the techniques applied for immersive moderate motion design (walking simulation - video resources with locomotion vs direct teleportation);
- the comparative assessment of the techniques applied for navigation with location reference design (user of human actor vs graphic UI elements);
- the evaluation of the educational potentials and engagement level offered through the gamification of a Cultural Heritage storytelling experience using the 360-degree video medium.

The development of the prototype testbed application has followed the iVID framework approach defining and integrating some techniques, methods and processes for the experiential and interactive layers as depicted in the Figure 5. 1 below. The figure shows the specific part of the iVID taxonomic categorization used to define the methods and processes being evaluated in this phase of the studies. This focused evaluation procedure has been followed to allow the isolation of the methods and their study in a more targeted way. Integrating and evaluating all extracted methods using the iVID would lead to prototypes design of high complexity and made the whole process of the evaluation difficult to organise imposing the risk of performing a less systematic study. Therefore, UI design methods for HMD-based experiences (though UI elements have used) have been excluded from this study as they required a more focused and comparative evaluation which is addressed is the second phase studies (Chapter 6).

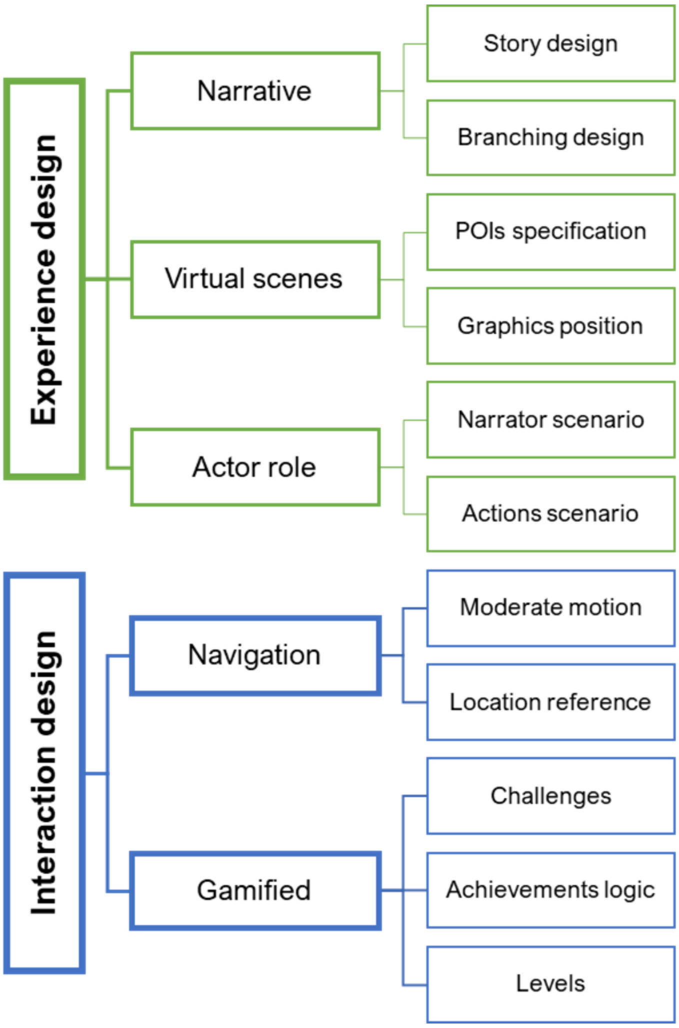


Figure 5. 1: Taxonomy of design aspects in experiential and interaction design layers addressed in the design of P1.

The following section presents the way iVID has been used to guide the definition of design methods for the development of the testbed prototype for the phase 1 of the studies (P1).

5.2 iVID-based methodological design for P1

To address the needs of the study, an immersive storytelling experience, an interactive 360-degree video-based virtual city tour of the historical centre of Rethymno, in Greece, has been developed. The application has been developed to be experienced using Oculus Rift VR headset.

Stage 1. Requirements analysis

The first phase of design analysis according to iVID is the analysis of specific design requirements for our prototype. The general design requirements have to adapted to better address the needs of the targeted application design. The requirements for P1 are listed below.

Dr1. Create a new form of 360-degree video immersive prototype application for virtual CH tours

Dr2. Create a 3D CH VE based on 360-degree video scenes as an Oculus VR application integrating a UI to support interaction;

Dr3. Integrate smooth moderate motion techniques for supporting scene-to-scene transition for a virtual tour;

Dr4. Use effective mechanisms and design approaches so as to not break immersion;

Dr5. Design a strong immersive virtual CH tour storytelling experience that engages the viewer with the story;

Dr6. Integrate effective and efficient navigation mechanisms to be able to guide the user around the 360-degree video scenes for spotting areas of CH interest;

Dr7. Use effective gamified design approaches applicable for the case of virtual CH tours with educational perspectives.

Stage 2. Experience design

The taxonomy at the experiential design layer provided by iVID has been used to define methods and design process that were integrated in P1 and subjected to user evaluation.

Narrative design methods: The Rethymno city has been chosen for this prototype application (P1) due to its great historical importance, preserving artefacts and monuments in good condition capturing historical periods spanning from the Ottoman to the Venetian periods (Digital Crete 2016). Those artefacts offered the opportunity for creating an interesting narrative experience by capturing city scenes at the Historical centre of Rethymno depicting the areas those artefacts are placed. t. The story design for the narrative aims to offer a strong storytelling experience motivating the users to learn about the history of Rethymno in a new and engaging form (Dr1, Dr5). The branching storytelling technique has been also applied offering the users the option to select different paths and navigate to a series of 360-degree video scenes discovering the historical areas of Rethymno in a different sequence and in a more exploratory approach. The branching storytelling paths design methodology is described in more detail in section 5.3.2.

Virtual scenes design methods: A set of POIs that are of historical interest have been specified to guide the creation of virtual scenes that depict them (Dr5). The POIs in our case are four well-preserved historical fountains from the Ottoman period. Text panels are selected to be also used to provide the necessary historical information about the artefacts (POIs) shown in each scene of the virtual tour. Those graphic elements should dynamically appear and positioned when the fountain is in front of the user's view. 3D CH VE based on 360-degree video scenes were created and enriched with UI graphic elements (Dr2) depicting important historical textual information about the captured artefacts (Digital Crete 2016).

Actor's role design methods: The method for using a human actor performing as a narrator has been selected and applied in the first scene of the prototype (see section 5.3.1). The scenario of the actions and speech the actor performs has been also defined before moving to the video resources production phase. The actor is captured to tell a short story about the history of Rethymno and introducing the user to a mission defined for the tour. The approach aims to provide a more realistic interaction and influence the user making them more interested in the context of the story and the experience. Another actor has been also used as a method to provide a more realistic motivational technique for the users to rotate their view towards the direction of the fountain in the 360-degree scene (Dr4, Dr6).

Stage 3. Story design

The user journey and video scripts specification are produced at this step. Six short-time 360-degree video scenes, one per area of interest, have been produced through videos captured in first person view depicting the user standing in the middle of each scene, or in front of a specific POI (a historical building or artefact), to allow the exploration of the place. The design of the overall P1 experience is shown in the Figure 5. 2 below in the form of a user journey diagram with the coloured circles expanding around the user representing the different scenes and the green bullets depicting the different locations of the POIs.

The recording of the 360-degree video content was done with a Ricoh Theta S (2016) camera device that consists of two 180° FOV cameras and is accompanied by a software editing application that allows automatic stitching, manual editing and export to .mp4 format. The use of a low-cost low-quality camera was due to limitation in cost and the objective that the research output will have impact on a wider community using cheap cost equipment to create 360-degree immersive experiences. Those exploratory video resources have been used to create mixed media virtual scenes enriched with UI graphic elements depicting important historical textual information about the captured artefacts (Digital Crete 2016). When the users manage to reveal this information, they can proceed to the next level of the experience. The level-up design approach is provided in the form of the 6 expanding circles in Figure 5. 2.

Two actors have been captured in the scenes: one providing introductory information and narration at the start scene (orange element N in Figure 5. 2); and another one for motivating and directing the user to look at specific areas in the scene to discover the artefacts to be found and reveal relevant historical information (orange element H in Figure 5. 2).

Branching storytelling is integrated in Scene2 - Scene4 (see Figure 5. 2), following the introductory scene (Scene1), offering the users the option to navigate to a series of 360-degree video scenes and discover the captured POIs in a different sequence. Through integrated UI interaction panels and buttons, the users are offered different paths to follow by selecting the transition gate of their preference and move to the corresponding fountain scene (blue bullets in Figure 5. 2). After all POIs and information have been discovered the user is directed to the last scene (Scene5) where only one, the most important historically, artefact can be visited.

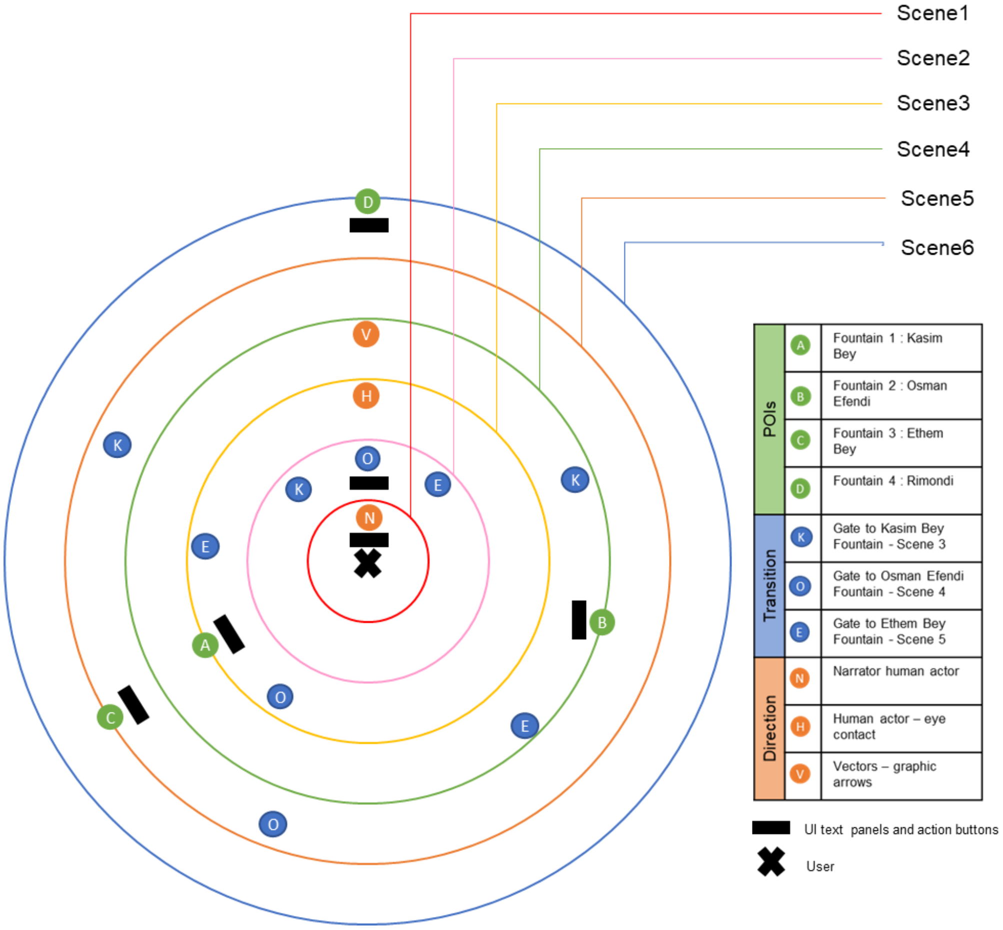


Figure 5. 2: User journey diagram specifying the design of P1 experience

Stage 4. Interaction design

Navigation design methods: Different moderate motion techniques to support the transition from one scene to another were incorporated in the design process, such as walking simulation and direct teleportation (Dr3). The walking simulation refers to the capturing and integration of videos where the subject has the sense of being moved through walking down an alley before moving to the next scene. In contrast, with direct teleportation the user is instantly transferred to another area through direct change of static captured video resources. In the Figure 5. 3 below, an example is displayed of walking simulation used from O to E and scene2 to scene3 transition and direct teleportation offered from transitioning form scene3 to scene4 using E to K UI gate elements. Graphic arrows have also been integrated in a specific scene to assist the user to spot the fountain in the 360-degree scene (Dr3) and address location reference (orange element V in Figure 5. 2).

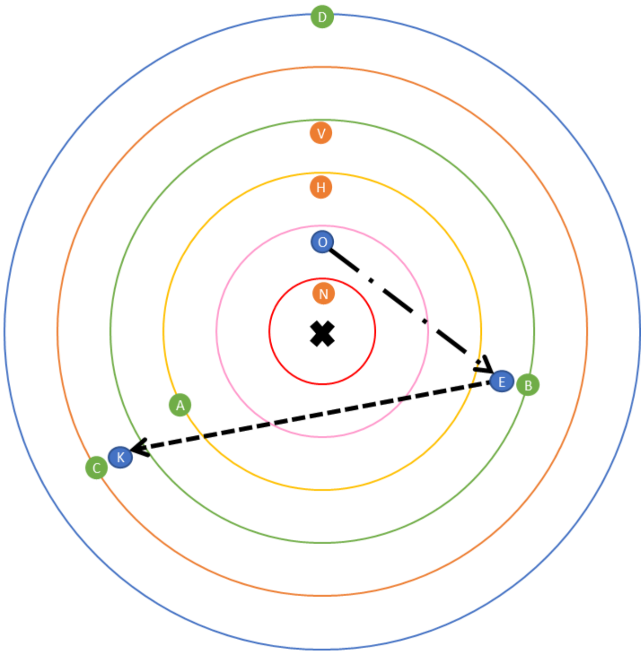


Figure 5. 3: Walking simulation vs direct teleportation

Gamified design methods: The experience had been designed as a gamified, educational tour, revealing information about the city in a fun and engaging way (Dr7). The player is informed by a narrator that will play the role of an Ottoman soldier missioned to collect as much water possible from several historical fountains of the Ottoman period, which remain in the city, and carry it to the most important fountain of the city, the Rimondi fountain (Rimondi, 2016). The role of the Ottoman soldier has been mentioned with the aim to create empathy with the mission and the context of the story as there is no evidence on user embodiment when experiencing the video scenes captured in first person view. In this journey the user is presented with the challenge to spot three fountains (gradually – levels design approach), discover relevant historical information and reply to a set of questions (achievements logic) in order to collect water for the Rimondi fountain (final level). The game ends after the user has visited all fountains and reached the Rimondi area, where the players are addressed with a Gold, a Silver or a Bronze badge of the Ottoman citizen of Rethymno according to the points collected throughout the tour following an achievements technique incorporation.

Feedback on user progress is given through a Water collector indicator UI element showing the users’ current score (see section 5.3.3 Figure 5. 11)In that way the users are learning about the history of the city by completing a set of tasks and challenges that allow the interaction with the VR environment. Challenges are continuously presented to the players at each level of the game, keeping them curious while testing and applying their knowledge. Addressing challenges makes people feel they have earned their achievement giving them the sense of accomplishment which is one of the eight core drives of gamification according to the Octalysis gamification framework (Chou, 2013).

The logic of the overall gamified experience is designed based on the concept of exploratory games that allows users to freely navigate and visit several stages of the game by experiencing different narratives till they identify and complete all challenges presented (De Valk, 2012). The exploratory approach triggers the users’ curiosity motivating them to master the rules and affordances of the game by supporting them to level-up and advance in the game, making the whole experience more engaging.

Stage 5. Scenes design

At this stage the output of the previous ones is studied to proceed with the mapping of methods that should be applied in each of the video scenes and produce a specification of the interaction logic that should be incorporated following a gamified approach as also a definition of the required graphic elements to be used.

Methods per video scene categorization:

In order to serve the purpose of this study, the research instrument (the 360-degree immersive video Historic Rethymno virtual tour) has been designed following the methods defined at the previous stage of the iVID framework. Those are depicted in different colour codes in Table 5. 1. below (green for navigation-location reference design, orange for moderate motion design, purple for gamified design and blue for the motivational elements that may trigger user choice). Each scene of the testbed integrates relevant design elements falling in different categories of the experiential and interactive layers captured in Figure 5. 1. The top row of Table 5. 1 indicates the scenes and the scene content, while the columns the design methods integrated per scene. How the methods were applied in each of the scenes is detailed in section 5.3.

Design method	Scene1: Intro	Scene2: Path selection	Scene 3: Fountain 1	Scene 4: Fountain 2	Scene 5: Fountain 3	Scene 6: Rimondi
Human guided navigation			✓			
UI guided navigation				✓		
No navigation support					✓	
Walking simulation		✓				
Teleportation			✓	✓	✓	
Score indicator			✓	✓	✓	✓
Educational questions			✓	✓	✓	
Badge indicator						✓
Actor narration	✓					
Branch selection		✓	✓	✓		

Table 5. 1: Design methods applied at each scene of the 360-degree immersive video Historic Rethymno virtual tour.

Interaction and game logic specification:

For the development of the overall game logic it is important to track the users' actions in order to update the virtual environment accordingly providing user adequate system response.

Aiming to update the game scenes and UI elements accordingly, while providing accurate feedback, the following game variables have been created:

- **current score** – for recording the user's score;
- **user's answer selection** – for defining if the correct answer was spotted immediately / after one wrong selection / after two wrong selections;
- **final score** – for defining the final achievement level and badge assignment;
- **current scene** – to know at which scene the user currently is;
- **current Path selection** – for the defining the next path choices that should be revealed;
- **current Path options –** the available path options;
- **time spent till spotting Fountain with Human assisted navigation;**

- **time spent till spotting Fountain with UI assisted navigation;**
- **time spent till spotting Fountain with No navigation support;**

The last three variables recording the time spent by the user to spot the POI (fountain), using different navigation assistance techniques, were created for further data analysis.

The game consists of a series of events as shown in the Figure 5. 4below which demonstrates the overall gameplay logic, the required user input and the GUI updates. The orange part refers to input information either though the user interaction with the UI or the HMD device sensor data (based on the user head movements in the real world). The green part is about the updates in the virtual environment (scene/interaction element updates) according to the input data. At last, the blue part includes the integrated UI element dynamic updates on information displayed based on the scene updates and user selections/actions.

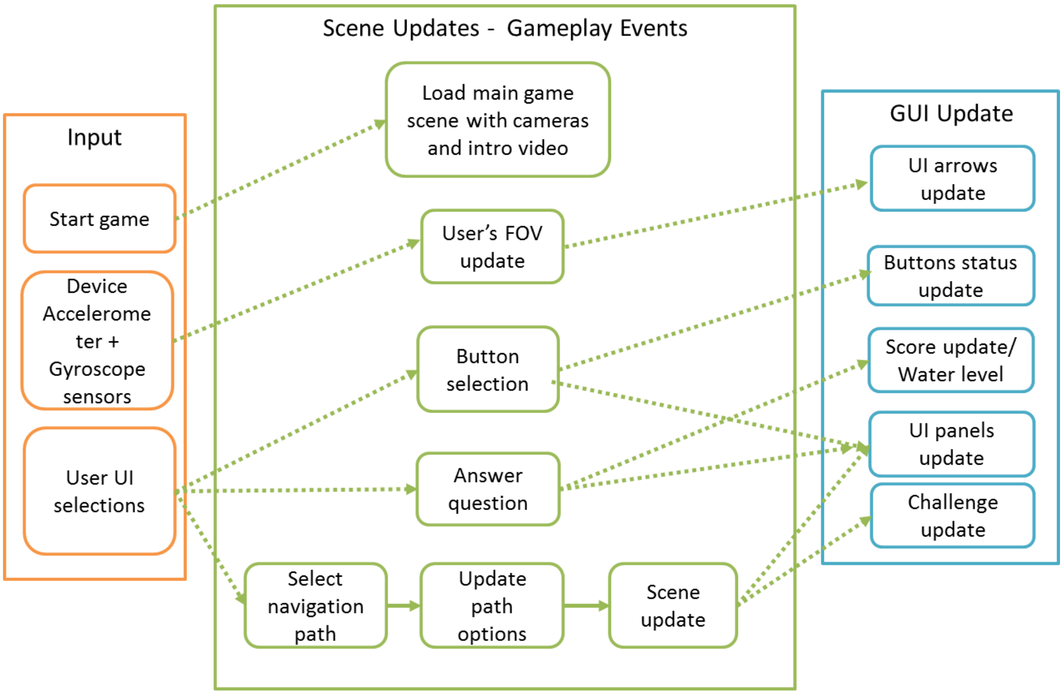


Figure 5. 4: Gameplay logic

Graphic elements design specification:

Textual information has been also communicated in the form of 2D panels integrated in the scene. That information referred to instructions about the interactive tasks of the experience, or the provision of historical facts and multiple answer questions. The panels appeared directly in front of the user's view (or in front of the POIs/artefacts) taking approximately 1/9 of its field.

To assist panels with instructions legibility, those were designed with white font colour for the text on dark grey background that appeared semi-transparent on top of the scene video content (see Figure 5. 6and Figure 5. 12). In contrast, the panel with historical questions and information to be distinguished from the instruction and buttons appeared as on a box with papyrus texture (see Figure 5. 9, Figure 5. 10,Figure 5. 16). In the case of having more than one instructional panel in the scene (necessary for the branching storytelling design), panels were positioned next to each other taking into consideration that all available options should be partly visible to the user's field of view when entering the scene (see Figure 5. 6).

5.3 Prototype development

The first prototype consists of a 360-degree video based interactive application that was designed to serve a set of different test scenarios so as to allow the evaluation and comparative study of different design techniques (Bowman et al., 2001). Those scenarios were running at each different scene of the interactive storytelling tour experience.

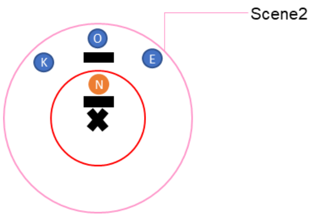
5.3.1 Scene 1: Intro

At the first stage (Scene1 of Figure 5. 2), the users are placed at a historical courtyard were a Turkish woman, serving the role of the narrator, is welcoming them (see Figure 5. 5), introduces the history of the city and explains their mission.

Figure 5. 5: First scene – Intro

5.3.2 Scene 2: Path selection

Moving on from scene 1, the user is transferred to a new virtual scene, at the old city of Rethymno, in front of a crossroad path, where introductory UI panels appear presenting the first task to be completed asking the user to select a fountain to visit (see Figure 5. 6). The interaction with the UI elements is gaze-based. This means that the UI buttons appearing in the scene are triggered by focusing on them for a few seconds followed by a green filling effect as depicted in the figure. A short walking video follows resembling locomotion and moving the user towards the path selected transferring them to the scene of the corresponding fountain (though the relative UI-gate element, K, O, E).



There are three fountains that the users should visit at a sequence of their preference according to their selections. Those fountains are placed in different areas of the historical city center dated from 1863 (Comerford, 2012):

- Fountain 1: The fountain erected in Patriarchou Grigoriou Street by Kasim Bey;
- Fountain 2: The fountain in Prevelaki Street erected by Yunus Aga’s son, Ethem Bey;

- Fountain 3: The fountain at the corner of Smyrnis Street and Koronaiou Street, built by Osman Efendi.

At each of the fountain scenes, the users experience a different technique that intends to guide them to spot the historical fountain by motivating them to change (rotate) their view.

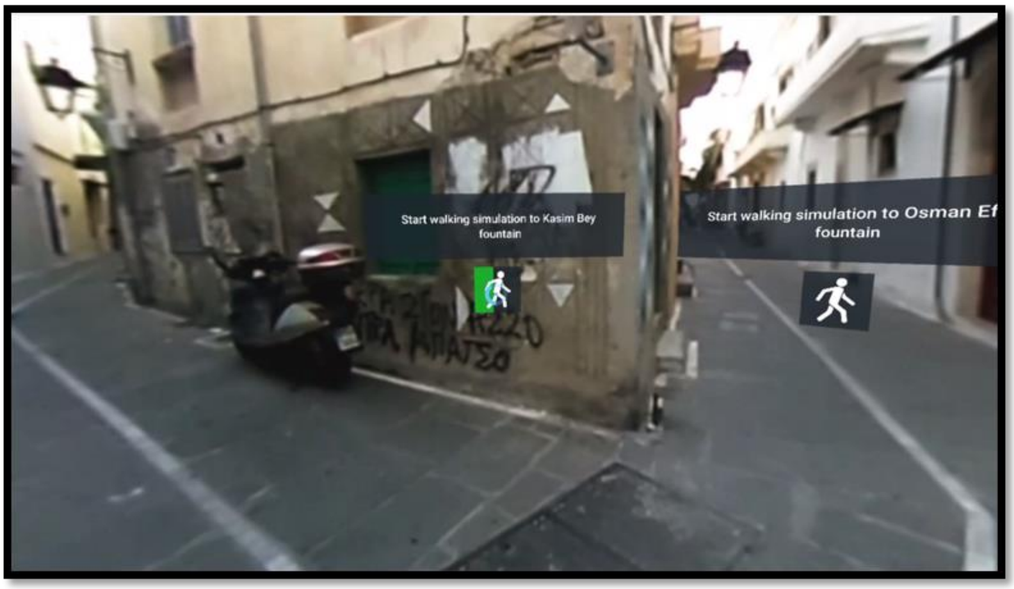
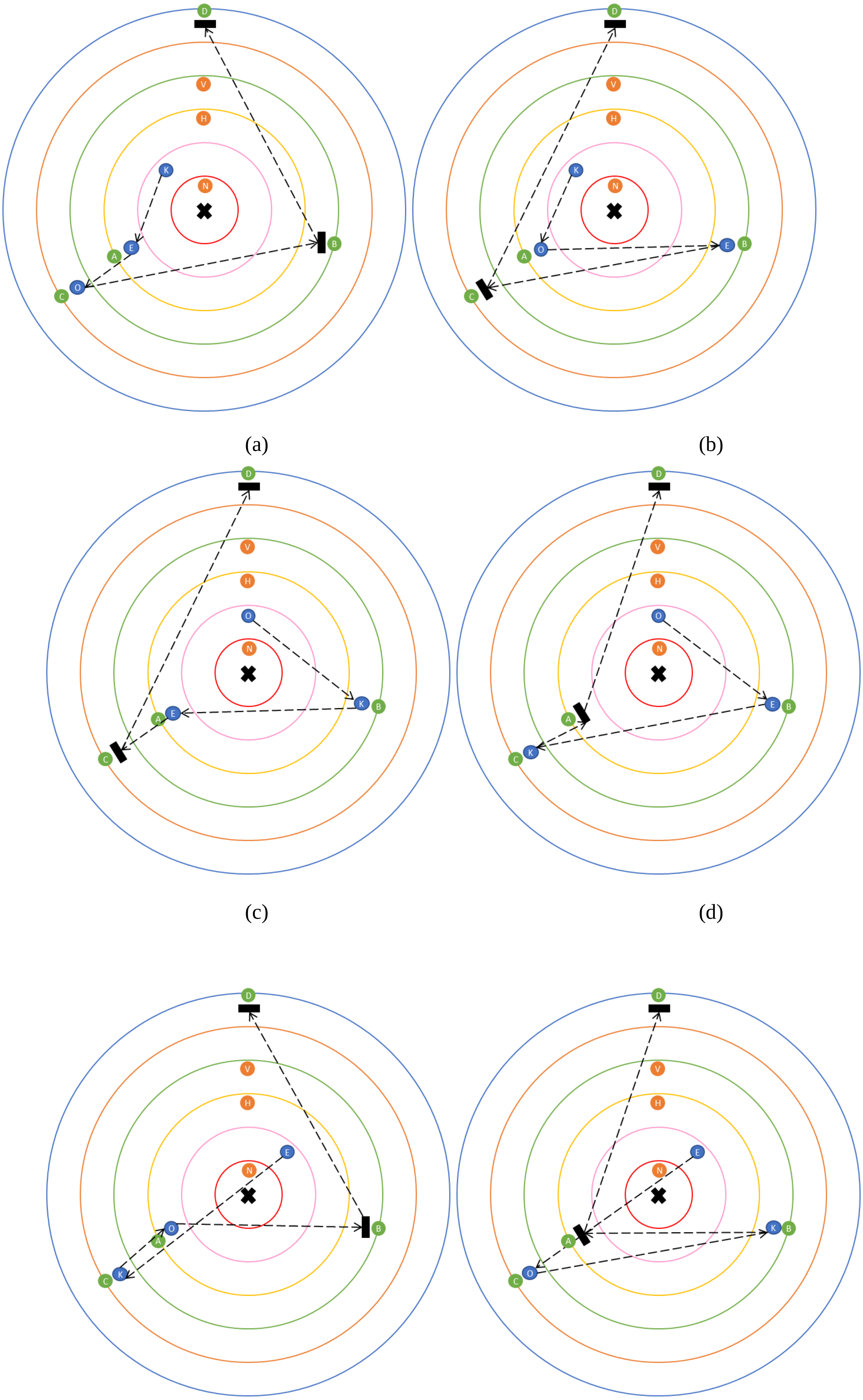


Figure 5. 6: Path selection scene

In scene 2, the branching storytelling design has been applied though a non-linear story design offering 6 possible paths for vising scenes 2-5 and allowing users to choose their preferred path to experience the story/narrative. The 6 different paths offered are shown in the hero’s journey diagrams of Figure 5. 7 that follows.



(a) (b)

(c) (d)

(e) (f)

Figure 5. 7: User journey options based on the branching design applied in P1.

5.3.3 Scene 3: Fountain 1 – Human assisted navigation

In scene 3 the navigation is supported by a human actor, meaning that there is a person in the scene creating a human contact with the subject who turns towards the fountain to motivate the user to also turn and figure out what she is looking at (see Figure 5. 8 and orange element H).

When the user turns towards that direction, a panel with a challenge in the form of multiple answers appears (UI black element in front of green element A – fountain), providing also further instructions on how to move in the story.

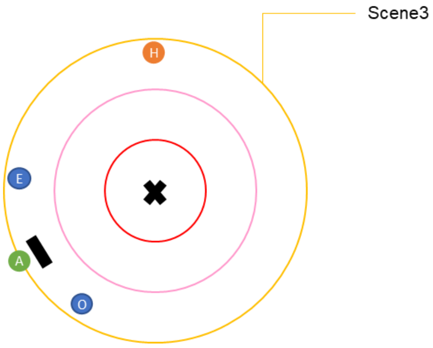


Figure 5. 8: Human assisted navigation

The user must select a UI button that appears below the question to choose the correct answer. When an answer is wrong, the button is marked red to indicate error and the user must select another button till the correct one is revealed and turned green, as shown in Figure 5. 9.

How many fountains did the Yunus Aga family build in Rethymnon around 1863-1864?

Figure 5. 9: User selecting the correct answer spotted second

A congratulations text communication panel follows revealing the number of litres of water gained. The water litres are calculated based on the number of attempts the users take to answer a question correctly (30 points are gained if a question is answered correctly at first attempt, 20 points at second attempt and 10 points when it is revealed by the system) (Figure 5. 10). The user should then select to collect the water gained and a graphic animated pot appears to be filled gradually based on the litres translated percentage (Figure 5. 11).

As a follow up step, the panels show the available options for choosing the next fountain to be visited (Figure 5. 12 and blue UI-gate elements O, E). The user must select the teleportation button (that has a relative graphic design different from the walking simulation) (see Figure 5. 13) to be transferred to the selected scene, meaning that the corresponding video resource is enabled and played.

Well done!
You successfully gained 20 litres of water

Figure 5. 10: Congratulations message indicating litres of water gained

Figure 5. 11: Water pot animated graphic UI element

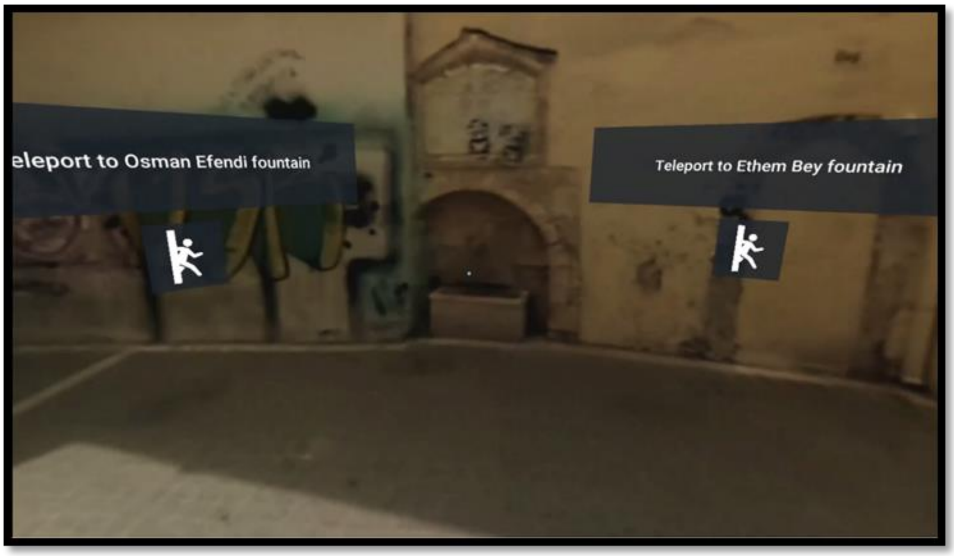


Figure 5. 12: Moving to second fountain options with teleport icons

Figure 5. 13: Teleportation icon selected

5.3.4 Scene 4: Fountain 2 – UI assisted navigation

In scene 4, the user experiences a new navigation assistance technique in the form of dynamically triggered pointing vectors that fade when the user turns to the fountains position (as shown in Figure 5. 14–Figure 5. 15and orange element V). A new multiple-choice question appears then (Figure 5. 16) and when the correct answer is revealed the scene is updated showing the score indicator element. The next panel directs the user to be teleported to the final fountain area depending on the previous path followed (see Figure 5. 17 and one of the blue UI-gate elements).

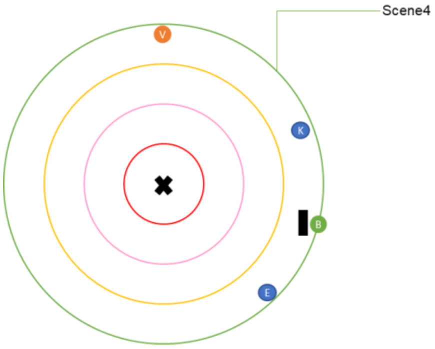


Figure 5. 14: UI assisted navigation technique through dynamic vector assets

This fountain was originally erected in 1863 by Yunus Aga's son, Ethem Bey, and consists of a large plinth, four recesses crowned by low arches, and an inscription with a fine carving.

Figure 5. 15: Dynamic vector assets fading when fountain spotted

The family of Yunus Aga offered another important building to the Ottomans of Rethymnon in 1892-1893. This is:

Figure 5. 16: Multiple answer challenge panel

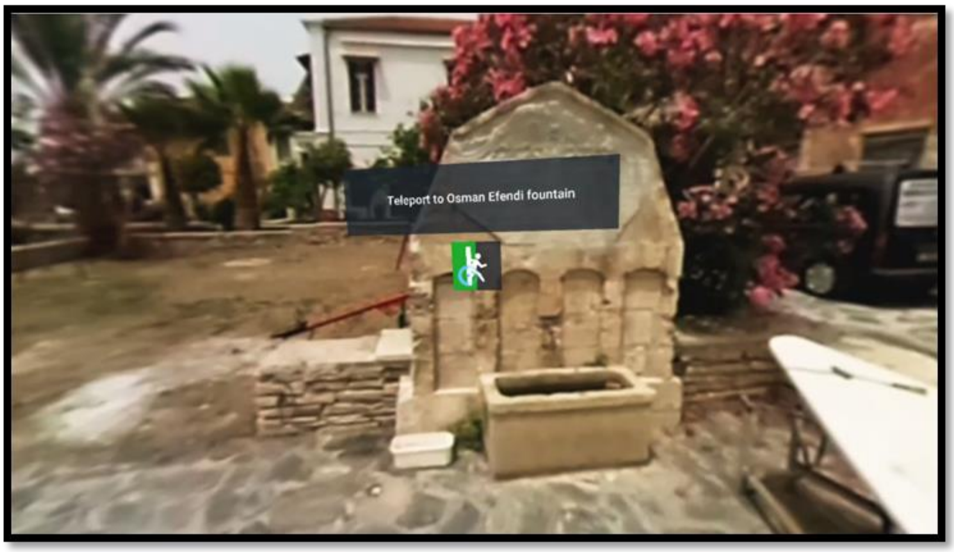
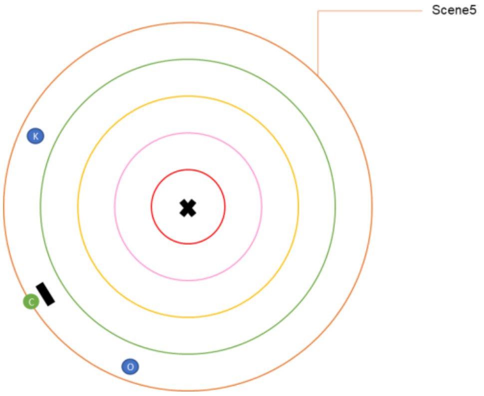
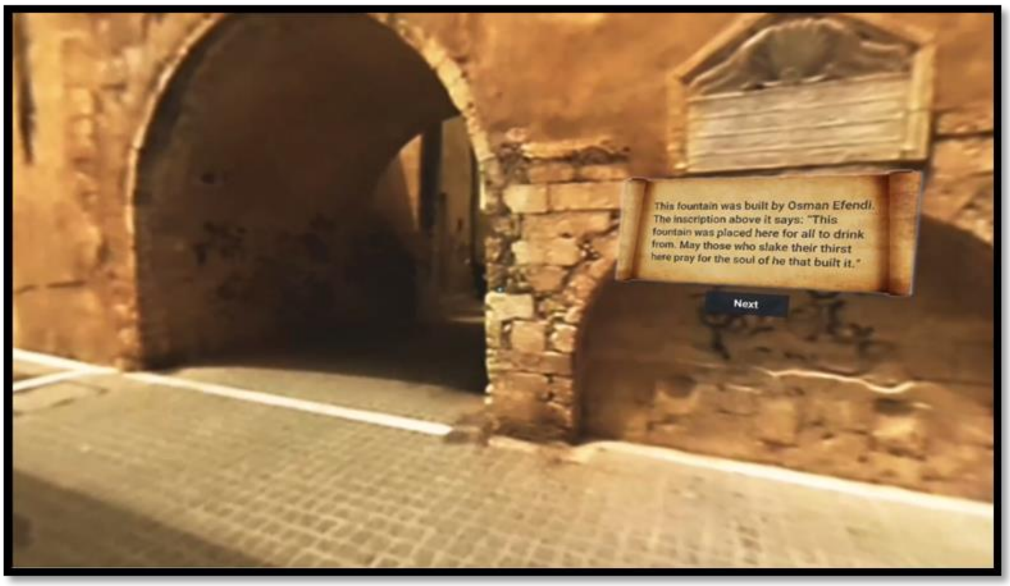


Figure 5. 17: Final single option panel to teleport to the last fountain

5.3.5 Scene 5: Fountain 3 – No navigation support



In scene 5, no navigation technique support is provided, and the users should spot the fountain on their own. The fountain is located on its back - right side (green element C) and it’s not visible at its viewshed when entering the scene. When the fountain is spotted by the user, the corresponding information UI text panel appears (Figure 5. 18) followed by another multiple-answer question panel (see Figure 5. 19). In case that this fountain is the last of the three visited, the user is requested to move to Scene 5 and visit the last fountain, Rimondi (see Figure 5. 7b, c user journeys).



This fountain was built by Osman Efendi. The inscription above it says: "This fountain was placed here for all to drink from. May those who slake their thirst here pray for the soul of he that built it."

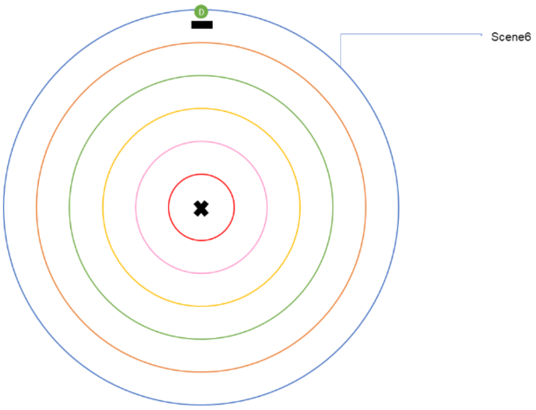
Figure 5. 18: Baseline fountain scene with no navigation support mechanism

What were the fountains used for in Ottoman times in Rethymnon?

Figure 5. 19: Reveal of correct answer after two errors

5.3.6 Scene 6: Rimondi – Final scene

When all the fountains have been visited and all questions are answered the user is teleported to the last scene of the experience. This is the most iconic fountain of the city of Rethymno, the Rimondi fountain (green



element D), which is shown functional with water running from its three tabs, indicating that the mission has been accomplishment. A text panel appears informing the user that the mission has been completed and that he/she has helped in the hydration problem of the city through a certain amount of water according to the score level achieved (as shown in Figure 5. 21). Based on the final score, a citizen badge is assigned to the user that is either bronze (up to 30 litres), silver (40-60 litres), or gold (70 and over litres).

Congratulations! Your mission is complete. You helped in the hydration problem of the city by collecting 50 litres water and gained the Rethymno Citizen Silver Badge!

Figure 5. 20: Final scene indicating the silver badge assigned after collecting 50/90 litres

5.4 Study design

This section provides a description of the study planning and the experimental environment setup for conducting the test involving real users and collecting the necessary data to address the research questions. Specifically, it describes data collection methods and tools used and the controlled environment settings and equipment. Ethical approval for conducting the studies has been also formally acquired by the University (further details provided in Appendix III).

5.4.1 Data collection methods

The data collection process included a set of different and comprehensive methods:

- A *Logging mechanism* integrated in the Rethymno 360-degree immersive video application was recording quantitative data during runtime to study each participant’s response time in completing the task of identifying the fountains. This has been accomplished through a script, integrated in the Oculus application, that calculated the time from entering a scene (and the reveal of the navigation assistance mechanism – human eye contact motivation/graphic vectors/baseline) up to point of facing the fountain contained in the scene and written to a .csv file.

- *Structured questionnaires* with two sections recorded (see Appendix I.1):

PART A) **demographic data** and **subject preferences**;

This part of the questionnaire focuses on collecting data on the users’ prior experience, habits, age range and background.

PART B) data capturing the **overall user experience**.

This part of the questionnaire consisted of 20 questions targeting the collection of data related to:

- sense of presence and user satisfaction of the immersive experience;
- preference of design techniques and elements integrated in the different scenes;
- user acceptance of techniques applied;
- user level of engagement with the overall experience.

Each question has been defined corresponding to a specific factor measurement related to:

- immersion, such as sense of presence, realism, naturalness, consistency and loss of time awareness; and
- engagement, such as endurability, confidence, novelty and focus of attention.

A 5-Likert frequency scale (1: strongly agree, 5: strongly disagree) that uses fixed choice response formats designed to measure attitudes or opinions (Bowling 1997; Burns & Grove 1997) is used.

- *Note taking* during conducting the test collected qualitative information about the participants overall experience, marking down issues of malfunction and difficulties in using the application and the required equipment.

- *Face-to-face interviews* following each task capture the participants' comments about their overall experience.

5.4.2 Experimental conditions

The experiments run in the mixed reality lab at the School of Computer Science & Engineering, at the University of Westminster that provided the required VR equipment and a safe environment for conducting the study (Figure 5. 21).

The VR equipment used were:

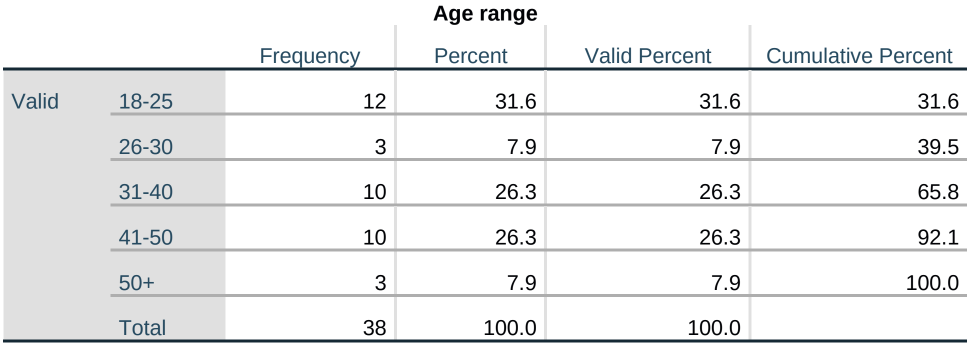
- one PC able to handle the tethered Oculus VR headset (1080x1200 per eye Resolution, 110° FOV, 90Hz Refresh Rate);
- an audio recording device to record interviews followed each session.

Figure 5. 21: Participant testing the application using Oculus

The study duration was three days, dedicating 30 minutes timeslots for each participant. All users have tried the application using the Oculus VR headset. The order the scenes experienced was random as it relied on the user's choices during the branching narrative. Each VR tour experience lasts approximately 7 min. Prior to the main session the researcher introduced the scope of the study and disseminated an information sheet and a consent form to be completed. At the end of each session the participants were asked to complete a scaled 1-5 questionnaire that took approximately 5-10 minutes to be completed, that collecting data related to the participants' experience in terms of immersion and engagement. The session ended with a short interview of the participants about their overall experience that lasted approximately 5-10 minutes.

5.5 Participants

Thirty-eight (38) users of mixed gender (23 males, 15 females) and ages spanning from 18-50+ participated in the study (see Figure 5. 22) on a voluntary basis invited through e-mails sent to University lists. 39.5 % of the participants were under thirty (18-30 years) while the 60.5% of them were between 31 up to 50+. Most of the participants (71.1 %) were undergraduate, post-graduate students, academic staff and professionals with a background in Computer Science and related studies (design, HCI) while the rest had non-related technology back-ground, such as psychologists or administrative staff.



Age range

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18-25	12	31.6	31.6	31.6
	26-30	3	7.9	7.9	39.5
	31-40	10	26.3	26.3	65.8
	41-50	10	26.3	26.3	92.1
	50+	3	7.9	7.9	100.0
	Total	38	100.0	100.0	

Figure 5. 22: Age distribution of the sample

More than half of the subjects (57.9 %) were frequent game players, playing games at least on a monthly basis and 71.1% has had at least one VR experience in the past (see Figure 5. 23).

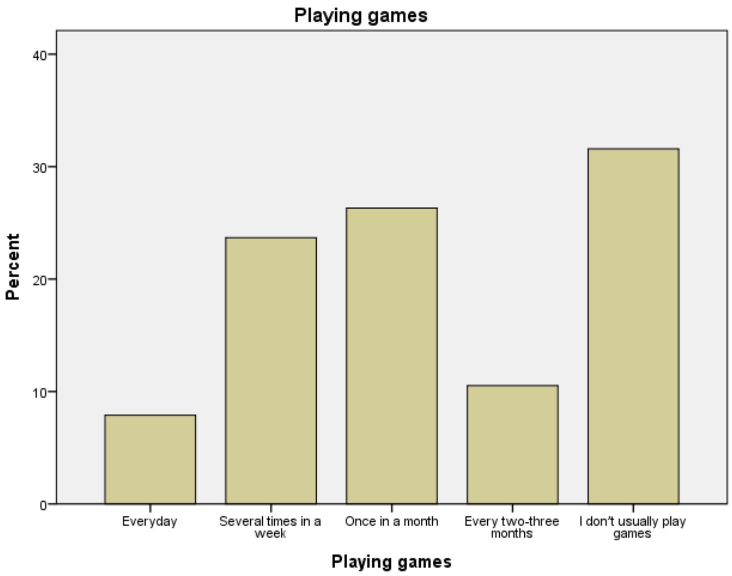


Figure 5. 23: Analysis of the participants profile in games playing

5.6 Data analysis

5.6.1 Methods for data analysis

The questionnaire generated non-parametric and categorical quantitative data that were mostly ordinal, but also nominal in some cases (gender etc.). In contrast, the data collected from the system logging mechanisms generated scale measurements and were analysed with most common non-parametric analysis tests equivalent to repeated measures ANOVA tests.

The organisation and analysis of the quantitative data collected through the questionnaires and the logging mechanisms integrated has been made by using SPSS. That leaded to the creation of 51 variables of scale, nominal and ordinal measure types that were defined and categorized as follows:

A. (3 variables – see Appendix Figure I. 2 SPSS rows 49-51) The integrated log mechanisms generated scale data (see Appendix Figure I. 5) for the time recorded in seconds for each of the scenes 3-5 of the P1 where different user view direction mechanism have been applied (Human eye-contact, Vectors-graphic arrows, Baseline/No-support). Time variable for scenes 3, 4 and 5 refer to the time required for each participant to change its direction of view towards facing the fountain in the corresponding video motivated by the arrows and the human actor’s gaze direction respectively.

B. (12 variables – see Appendix Figure I. 1 SPSS rows 1-11 and Appendix Figure I. 2 row 48) Part A of the questionnaire generated ordinal data for the age of the participants, their background, habits in playing digital games and indication of previous VR experience and previous experience with several types of VR HMD devices (Oculus, Samsung Gear, HTC Vive, Google Cardboard, Other) and nominal for the gender and nominal for trying the protype wearing glasses or not (see Appendix Figure I. 3).

C. (36 variables – see Appendix Figure I. 1 and Appendix Figure I. 2 SPSS rows 12-47) Part B of the questionnaire generated ordinal data for each of the 36 Likert type questions targeting the assessment of the user experience offered by the corresponding design mechanisms integrated and design methods applied in terms of immersion, usability and engagement (Appendix Figure I. 4).

Following a thorough analysis of the quantitative data is provided, followed by an interpretation of the outcomes concluding with a reporting section on the qualitative data collected during the after-tests interviews.

5.6.2 Quantitative data

The following sections provide a more thorough analysis of the quantitative data, followed by an interpretation of the outcomes.

5.6.2.1 Usability evaluation

The analysis of the data collected from a set of questions related to usability of the design approaches that have been followed for the creation of the Rethymno 360 immersive video virtual tour (see section 5.2) is captured in Figure 5. 24and Figure 5. 25 below. Those figures show the means of a list of usability criteria with 95% confidence intervals, indicating that the provided experience achieved high levels on effectiveness, user satisfaction, ease of use, comfort and familiarity. The means and the lower and upper bounds of 95% confidence intervals fall close to 2 - equal to agree in all of the positive statements such as “It was easy to understand how to accomplish the game tasks/challenges” (see Figure 5. 24), and close to 4 - equal to disagree in negative statements such as “I could not easily accomplish what I was asked to do” (see Figure 5.

25). The mean value to the question related to the UI elements design “The user interface elements were distractive” is lower (3,46 with error bar slightly not overlapping the others) and closer to neutral pointing out for a further analysis of qualitative information collected from interviews following the test session (qualitative analysis – see section 5.6.3) to identify the reasons that the UI elements were distractive and provide guidelines for better design.

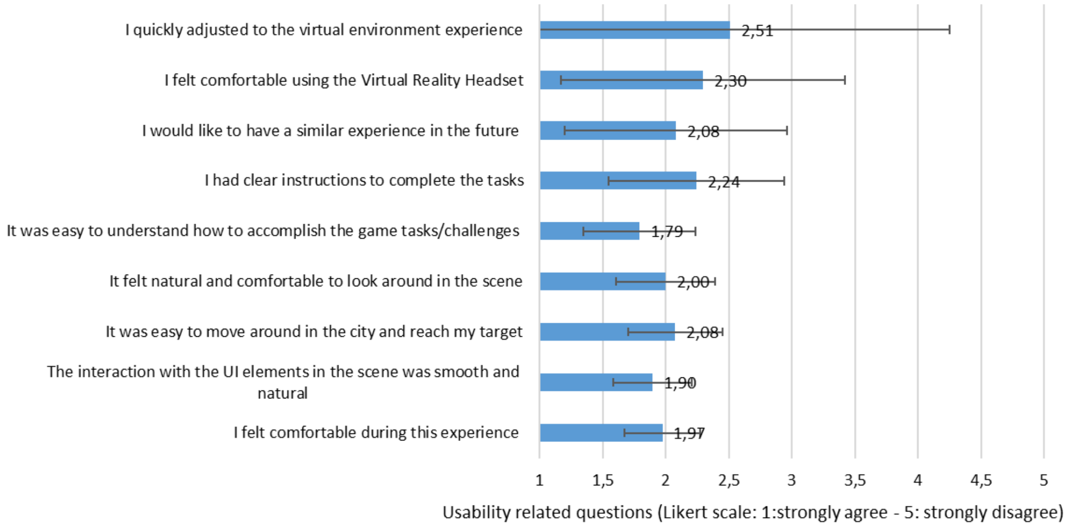


Figure 5. 24: Usability questions (part A) with 95% confidence intervals

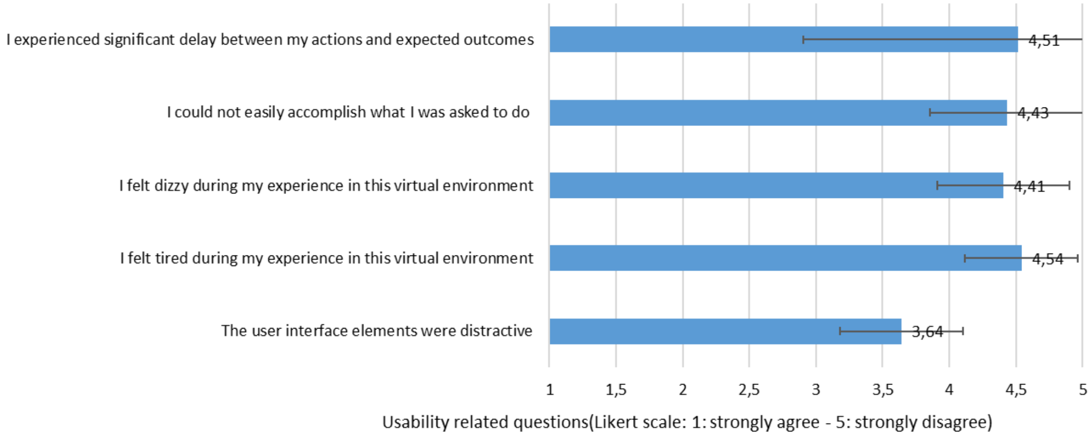


Figure 5. 25: Usability questions (part B) with 95% confidence intervals)

5.6.2.2 Immersion evaluation

To evaluate the level of immersion achieved using the Rethymno 360-degree immersive video virtual tour (P1), Figure 5. 26 shows the Likert scale means with 95% confidence intervals of questions related to sense of presence, realism, naturalness, consistency, and loss of time awareness. In terms of realism of the experience (mean value 2,26 close to

2-agree), "*feeling like actually being there*" (presence) and the achieved level of disconnection from the real world, the results confirm the hypothesis that the design that follows the proposed methodological considerations (see section 5.2) provides a satisfying level of immersive experience. The results related to loosing time awareness are neutral, the participants' replies vary, so no conclusions can be drawn related to the effect of the prototype design to offer such a sense. However, it is worth stating that besides the effect of locomotion integrated in the form of simulating movement through waking in the scene, the results indicated that participants did not feel dizzy. Dizziness is a feeling that breaks immersion (Kolasinski, 1995). This was achieved by capturing 360-degree video resources by holding the camera and walking slowly and steadily. Therefore, its potential for providing comfortable moderate motion while exploring 360-degree video is high.

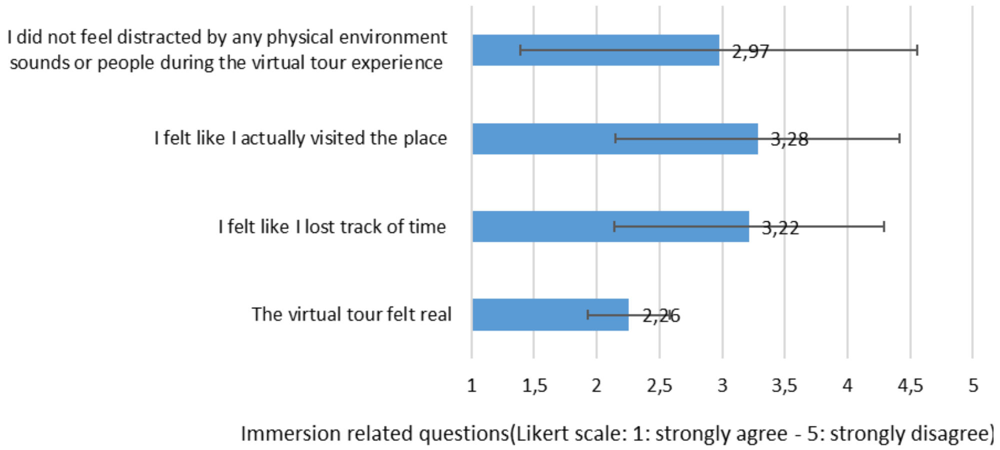


Figure 5. 26: Immersion questions with 95% confidence intervals

5.6.2.3 Engagement evaluation

In terms of engagement, the design of the Rethymno 360-degree immersive video virtual tour addresses the users' expectations. This is indicated by all related data from questions measuring factors associated to enjoyment, control, excitement, endurability, confidence, novelty and focus of attention had positive results (mean values close to 2-agree with error bars overlapping) as depicted in Figure 5. 27. Overall, the design approach showed good potentials in providing engaging experiences through the integration of branching narratives, gamified techniques, and moderate motion effects.

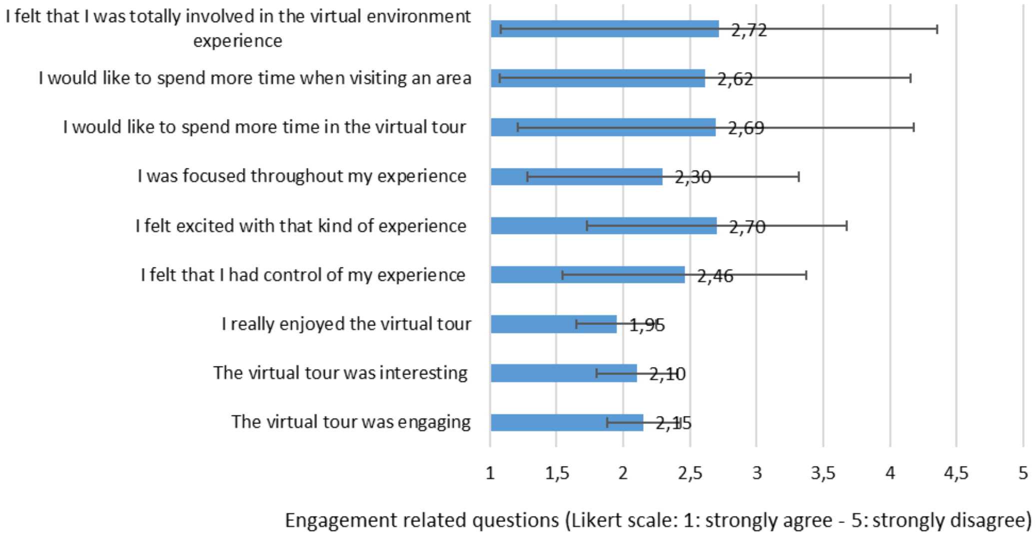


Figure 5. 27: Engagement questions with 95% confidence intervals

5.6.2.4 Moderate motion mechanisms comparative results

As depicted in Figure 5. 28, the results on questions related to the user's acceptability of the integrated navigation techniques from one scene to another indicate a preference towards the teleportation mechanism. The mean of the users' preference for walking simulation is 3,46 – closer to neutral. Thus, no valid assumptions can be formed regarding the most preferred technique for scene transition, but it can be concluded that the teleportation design offers a smooth and comfortable solution. Provided the results are neutral and not negative on the walking simulation (mean value 3,22 close to 3-neutral response), it can be assumed that there is potential for an acceptance also of this technique especially if the production of the videos is done with professional stabilization and higher quality equipment.

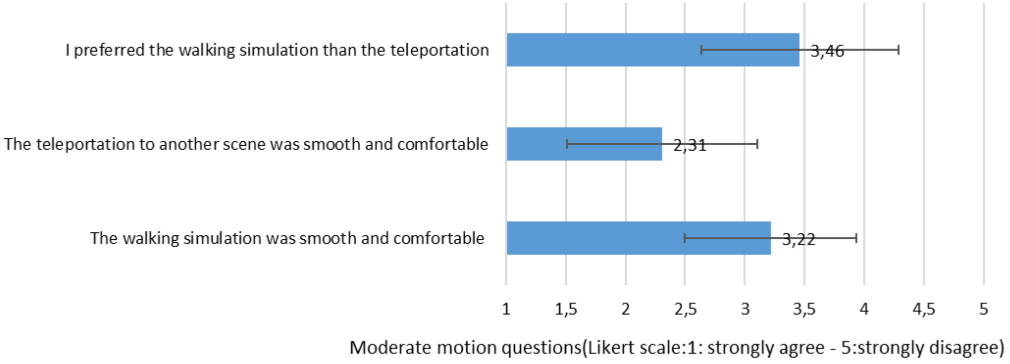


Figure 5. 28: Moderate motion with 95% confidence intervals

A crosstab analysis through Chi-square tests between the user's demographic and general profiling categorical data has been performed to check if there is a correlation with their indicated preference on the moderate motion mechanisms used (user's answers on the statement: "*I preferred the walking simulation that the teleportation*"). The Pearson chi-square test is a correlation test for categorical variables and essentially tells us whether the results of a crosstab are statistically significant. It is used when there two categorical variables independent (unrelated) of one another.

The chi-square tests of the analysis showed that there is no strong evidence of relationship (as p>0,05):

- between the users' age and moderate motion mechanism preference (Pearson Chi-square = 15,512, dF=16, p=0,488>0,05);
- between the users' habits on playing games and moderate motion mechanism preference (Pearson Chi-square = 12,065, dF=16, p=0,740>0,05);
- between the users' gender and moderate motion mechanism preference (Pearson Chi-square = 2,234 dF=4, p=0,693>0,05);
- between the users' experience in VR and moderate motion mechanism preference (Pearson Chi-square = 13,303, dF=12, p=0,347>0,05);
- between the users' background/profession and moderate motion mechanism preference (Pearson Chi-square = 7,169, dF=4, p=0,127>0,05);

5.6.2.5 Navigation mechanisms comparative results

Two navigation assistance techniques have been integrated in the Rethymno 360-degree immersive video virtual tour research instrument (P1):

- *Human motivation*: the integration of an actor in the video resource motivating the users to turn and look towards a direction the actor is looking by first creating human contact with the users and then turning and looking towards a POI;

- *Vectors UI:* the placement of directional graphic vectors that point to the direction of a POI and fade when the user turns towards the direction they point.

The results regarding the effectiveness of both techniques are very positive, with most of the participants stating that they strongly agree with the statement that they were motivated to change their view by those techniques (as shown in Figure 5. 29). In terms of user preference between those two techniques, there is no indication that users liked most one technique to another as the mean value of the corresponding question results is 3,1 showing neutrality. When participants have been asked if they would prefer no assistance to explore the environment at their own pace, the results were close to neutral (mean = 3,44) and therefore no accurate assumption can be formed based exclusively on that data.

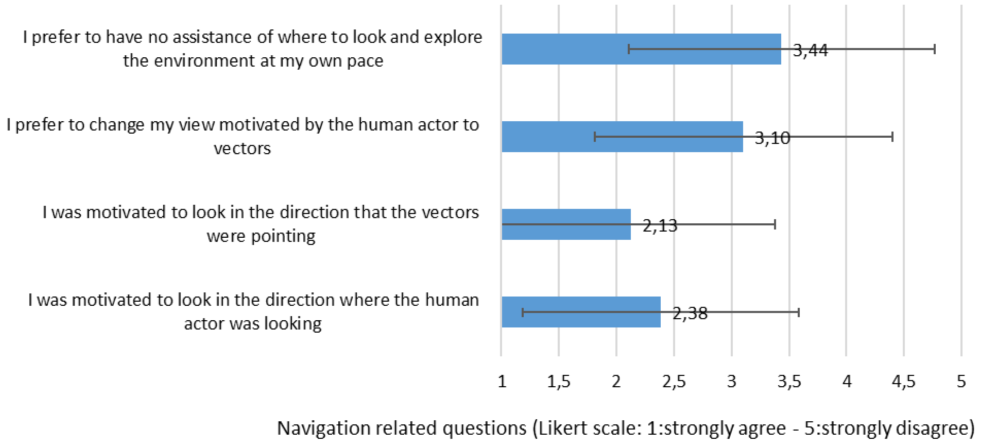


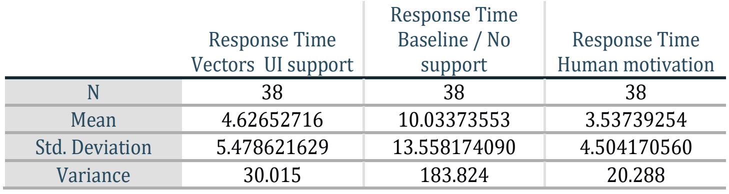
Figure 5. 29: Navigation means with 95% confidence intervals

To further evaluate the efficiency of the navigation assistance techniques a system log mechanism has been integrated in the testbed for Oculus, in scenes 3 (human motivation) & 4 (vectors UI), while in scene 5 no navigation assistance technique is integrated, forming the baseline. The log mechanism records the response time that takes the user to turn towards the POI (fountain) pointed by the incorporated navigation assistance technique. The data (see Appendix Figure I. 5) indicated that in scenes with navigation mechanisms the participants' response time was significantly shorter compared to a scene with no navigation mechanism (referred as Baseline/No support in Table 5. 5).

The hypothesis tested in this case is:

H0: There is no difference in the time it takes to identify the POI with the presence or the absence of navigation assistance mechanism.

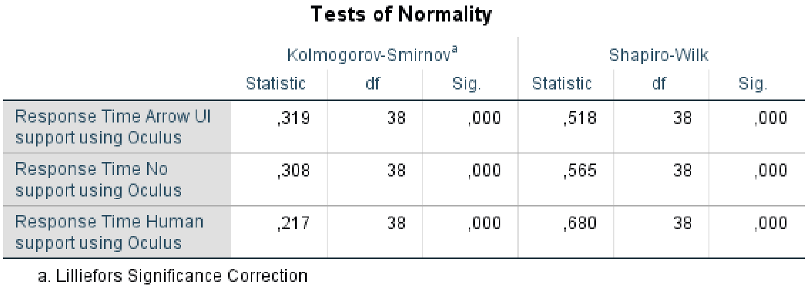
By comparing the different navigation mechanisms' response time means in Table 5. 2 below we see that the most efficient technique seems to be the Human guided navigation support, with a mean value of 3,53 sec. The less effective navigation mechanism is the baseline solution where no navigation assistance technique has been integrated, with a mean value of 10 sec approximately.



	Response Time Vectors UI support	Response Time Baseline / No support	Response Time Human motivation
N	38	38	38
Mean	4.62652716	10.03373553	3.53739254
Std. Deviation	5.478621629	13.558174090	4.504170560
Variance	30.015	183.824	20.288

Table 5. 2: Mean, standard deviation and variance of the log data for the different navigation techniques

However, the log time raw data is not normally distributed based on the significance results of Kolmogorov-Smirnov and Shapiro- Wilk tests (p=0) (see Table 5. 3). Thus, a full factorial ANOVA analysis is not allowed, and a non-parametric test should be performed. An equivalent non-parametric test is the Friedman's test that does not include though interactions analysis.



Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Response Time Arrow UI support using Oculus	,319	38	,000	,518	38	,000
Response Time No support using Oculus	,308	38	,000	,565	38	,000
Response Time Human support using Oculus	,217	38	,000	,680	38	,000

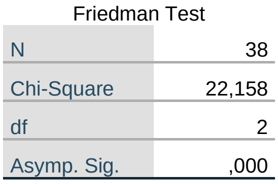
a. Lilliefors Significance Correction

Table 5. 3: Normality test of user time response to turn towards a POI driven by different navigation techniques.

The hypothesis tested in this case is:

H0: There is no difference in the time it takes to identify the POI with the use of a human vs the vectors navigation assistance mechanism

The nonparametric Friedman test exploring the differences among repeated measures on time revealed a significant (p=0) Chi-square value of 22.158 (see Table 5. 4). This points out for a significant difference between the two navigation mechanisms.



Friedman Test

N	38
Chi-Square	22,158
df	2
Asymp. Sig.	,000

Table 5. 4: Non-parametric Friedman test analysis for time repeated measures on the three navigation design techniques.

A post hoc analysis has been performed for pairwise comparisons using Wilcoxon signed-rank test among the different navigation assistance techniques (see Table 5. 5). From the Wilcoxon Signed Ranks pairwise comparison analysis it is evident that there is significant difference between the time performed with the Vectors UI technique in comparison to the Baseline/No-support (p=0,003<0,05). The users also performed significantly faster with the Human motivation technique than with Baseline/No support (p=0<0,05). There is no significant difference through on time to perform the task between the two techniques Human motivation – Vectors UI (p=0,112>0,05).

Wilcoxon Signed Ranks Test

	Z	Asymp. Sig. (2-tailed)
Time with Human motivation - Time with Vectors UI support	-1,588	,112
Time with Baseline/No support - Time with Vectors UI support	-2,980	,003
Time with Human motivation - Time with Baseline/No support	-3,589	,000

Table 5. 5: Wilcoxon Signed Ranks pairwise analysis of time

We can assume based on the repeated measures comparison results that the navigation mechanisms were both efficient comparing them to Baseline/No, but no conclusion can be made on which technique (human vs vectors) was most efficient in terms of navigation.

5.6.2.6 Narrative design results

The user acceptance level of the branching storytelling technique that has been adapted in the design of the Rethymno 360-degree immersive video virtual tour (P1), empowering the users with the choice to follow their preferred path to visit the next fountain (see section 5.3.2) was high. This is shown in the histogram of Figure 5. 30 providing the distribution of the users’ answers to the corresponding statement of the questionnaire. Most of the participants strongly agreed or agreed (30/38) that they preferred having the freedom to choose their own path to navigate to different scenes, with none of them disagreeing with this statement.

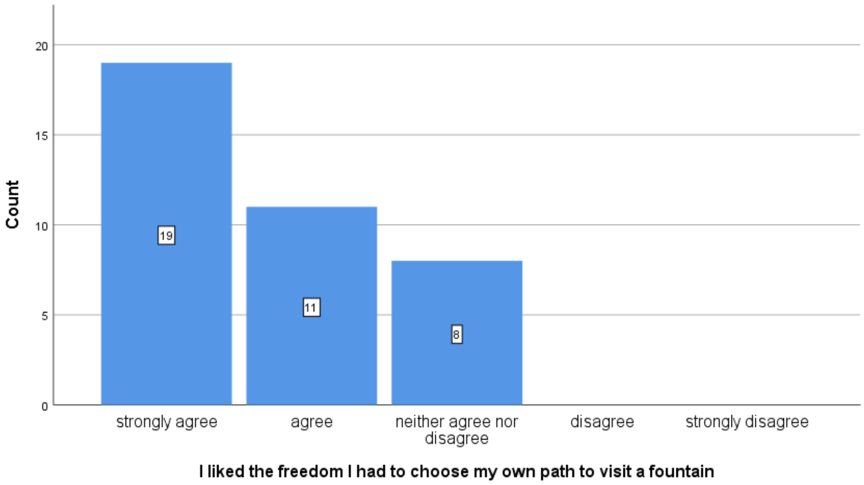


Figure 5. 30: Histogram of user answers relative to their acceptance of the branching storytelling approach

5.6.3 Qualitative data

Qualitative data have been collected while conducting the study through direct observation and notetaking and at a follow up interview after the completion of the session (see section 5.6.1). All the participants commented that the virtual experience was interesting, and they would like to have similar experiences in the future, as also that they were engaged and remained focused throughout the experience. They also pointed out that it was in general a comfortable experience with only a few of participants commenting that they felt a bit dizzy at some point when experiencing locomotion. In general, the participants commented that they would prefer a better quality of video, which was expected as the camera resolution used for the creation of the video resources was low. Some participants commented also on the position of the UI text panels by stating that the multiple-choice question elements where obscuring the fountains' view.

A significant number of the participants suggested that they would prefer a more relaxed experience of increased realism by using more human actors in different stages of the game. In addition, they suggested creating short walking simulations with intermediate tasks to feel like there were exploring the area at their own pace and feel more like truly walking in the streets of the historical city centre. Some of the participants also pointed out that they would like to be able to find clues that could help them in finding the right answer to the questions addressed and also that this could lead to an effective educational solution that they would enjoy.

5.7 Design guidelines

The interpretation of the outcomes of this study allowed the formation of assumptions on the applicability and usability of the design techniques integrated at 360 immersive video applications. Those assumptions could be generalizable to other forms of applications. In order to effectively integrate those techniques, a set of design guidelines (DGs) outlined below should be followed. Those DGs are presented in four parts: DG; motivation; benefit; examples, following a model suggested that DGs need to be precise and providing examples of use in order to reduce the chances of the guideline being too vague, or conflicting (Reisner, 1987; Economou, 2001). The DGs are grouped following the taxonomy of Immersive video design techniques and according the experiential and interactive layers of the taxonomy (see Figure 5. 1).

5.7.1 Design guidelines addressing the experiential layer

This section outlines a set of design guidelines that address the requirements of the experiential layer of the iVID framework in order to create immersive and engaging experiences in 360-degree immersive video.

5.7.1.1 Narrative design

DG1: The design of the story of the application should follow a real-life application scenario.

Motivation

The definition of the story of the immersive application around a virtual tour in a city of historical interest where participants had a mission to accomplish made the users more engaged to the context (see section 5.6.2.3).

Benefit

The design of the story around a real case scenario can increase the level of realism and make the users feel more immersed.

Example

In the Rethymno 360 immersive video virtual tour the user has the mission to collect water from the fountains visited as someone would do in a real case scenario of the past (see section 5.3.1).

DG2: The design of the narrative should follow a branching storytelling approach to further engage the user to the story.

Motivation

When experiencing a narrative, the users should engage with the context of the story and remain motivated till the end. The techniques of branching storytelling applied in P1(see section 5.2) reported high levels of engagement (see section 5.6.2.6). Given the choice to select their own path to experience a story empowers the user sense of ownership and control which is important also for increasing their sense of presence (Reeves, 1991).

Benefit

Designing a storytelling experience with a non-linear approach offers the users the sense of empowerment and control of the story leading to higher levels of engagement with the context. Branching storytelling if efficiently applied in immersive video narratives design is a promising methodology towards engaging the users further by offering them the choice of following a more personalized experience. In virtual tours created with immersive video the design of different paths to follow offers a more realistic experience as it simulates a real-world scenario.

Example

The Rethymno 360 immersive virtual tour was created applying the branching storytelling technique at the beginning of the experience. The users had to choose their preferred fountain location to visit next when being in front of a crossroad of the city (see section 5.3.2). The videos integrated in the crossroad scene had to loop while waiting for the user to select a path option though the UI panels. When capturing 360-

degree video scenes for such a purpose the scenery activity should be able to loop in a realistic way.

5.7.1.2 Virtual scenes design

DG3: Each virtual scene should depict a set of POIs relative to the story.

Motivation

Immersive video experiences should offer interaction with the virtual environment. Designing an immersive virtual scene by integrating 360-degree video resources requires the capturing of important elements such as humans, buildings, or objects relative to the story that should attract the viewers’ attention and allow the design of interacting with them (see section 5.6.3).

Benefit

The capturing of POIs in the immersive video that structures the virtual scene, or the integration of graphic elements allows the design of interaction around those POIs. POIs allow the design of the story to unfold around those and support the creation of interesting context and engaging interactions with the virtual environment.

Examples

For the design of the Rethymno 360 immersive virtual storytelling tour a list of immersive videos had been produced depicting historical fountains. The fountains served as the POIs in the virtual scenes created allowing the interaction with those, and the creation of a mission effectively engaged users with the story context (see section 5.2).

DG4: The UI graphic elements with textual information should be placed in positions close to the POIs but without hiding them.

Motivation

To encourage interaction in 360-degree video-based virtual scenes it is necessary to add UI spatial elements that request actions or provide textual information. The Gestalt principles of proximity stating that objects that are placed closer-together appear as being part of a group is also applied in VR environments (Valencia-Romero & Lugo, 2017). Those elements placed in the 3D space projecting a video resource may hide though important information displayed in the background (see section 5.6.3).

Benefit

Placing the UI elements providing textual information close to projected POIs by the video resource forming the virtual scene assists their correlation and provides a connection between the graphic elements and the video elements. It is important though to be placed in areas of the virtual scene that will not violate the observation of the video POIs.

Examples

UI textual information panels have been integrated in each virtual scene formed by a 360-degree video resource mapping in the 3D space of the virtual Rethymno experience (see section 5.2). Those UI elements displayed multiple choice questions for the user to interact with by selecting the correct answer. The elements were placed in front of the fountains displayed in the video and therefore hided the POIs of the virtual scene as pointed out by the analysis of the study participants’ comments (see section 5.6.3).

5.7.1.3 Actors role design

DG5: Human actors used as narrators in immersive video scenes should be provided with a scenario describing storytelling movements to perform as they speak.

Motivation

The use of a narrator in an immersive storytelling scenario can increase the sense of presence and make the experience more realistic. In order to effectively integrate such a motivational element in immersive video applications, an actor’s script for the narration should be produced and followed during the video production of the corresponding scenes. As noted by the qualitative data analysis the script should include engaging and realistic movements (see section 5.6.3).

Benefit

A well-designed realistic script for the narrator actor performing in immersive video can engage the user to the story, attracting their attention through movement and speech and lead to high levels of immersion.

Examples

The Rethymno virtual tour started with an actor's speech describing the context of the tour and the users' mission, making the experiencing interesting from the beginning and captivating their attention (see section 5.3.1). The users reported that more realistic movements and engaging performance would engage them further keeping them more focused on the narration (see section 5.6.3).

DG6: Human actors used as navigation motivators influencing the user's view rotation should be provided with a scenario describing the exact actions to perform to create human eye-contact.

Motivation

Human eye-contact in immersive video can be as effective as in real life making the users follow the subject. This could be used as a more realistic technique in assisting the users to locate POIs in immersive video scenes by capturing human actors looking at the same direction. The study results revealed that this technique is quite effective (see section 5.6.2.5). This complies with other research in VR that confirms the human mimicking behaviour following virtual humans' actions in VR (Da Silva et al., 2010; Hasler et al., 2014).

Benefit

The use of actors to create a connection with the viewer adds an element of realisms to the experience and can be an efficient technique in assisting users to explore the virtual space and locate POIs in the 360-degree VE. It can effectively eliminate also the users' fear of missing something important happening out of their view.

Examples

A lady actor has been integrated in an immersive video scene of the Rethymno virtual tour facing the viewer (see section 5.3.1). After a few seconds the lady turned to look towards the fountain that needs to be located. Participants were motivated by the human contact to turn and spot the fountain in the scene (see section 5.6.2.5).

5.7.2 Design guidelines addressing the interactive layer

5.7.2.1 Navigation design

DG7: Moderate motion effects should be integrated through short and steady walking simulation videos.

Motivation

Videos captured by walking steadily towards a direction for a short time are promising for increasing the user's immersion in a 360-degreevideo-based virtual experience (section 5.3.2). The study revealed interesting results on the use of such a moderate motion mechanism with participants commenting that they would like to experience immersive walking in more parts of their virtual tour (see section 5.6.2.4 and 5.6.3).

Benefit

Realistic moderate motion can be effectively addressed using short and steady walking simulation immersive videos instead of teleportation effects. The feeling of immersion increases while the experience remains comfortable for the users preventing nausea effects when experienced through a VR headset.

Examples

The participants experienced an immersive video short walking simulation guiding them towards an alley's crossroad at the historical center of Rethymno (see section 5.3.2). Results indicated comfortability with this technique.

DG8: Location reference of POIs can be effectively given though the integration of graphic pointing vectors.

Motivation

The requirement of the users to be navigated in the 360-degree virtual scene can be addressed through the use of graphic vectors pointing towards the location of POIs (see section 5.6.2.5).

Benefit

Graphic UI elements can effectively guide the users in locating POIs in a virtual scene. The use of UI elements in virtual worlds and games is a common user experience design mechanism and can provide the sense of familiarity in 360 immersive video applications.

Examples

Graphic UI elements in the form of pointing vectors have been used to provide reference of where the fountain is located in one of the 360-degree scenes (section 5.3.4) of the Rethymno virtual tour. The use of the vectors has proven to be an efficient and acceptable technique in navigating the viewers (see section 5.6.2.5).

5.7.2.2 Gamified design

DG9: Challenges can engage the users if integrated in each scene in the form of multiple answer questions on text panels.

Motivation

The introduction of challenges is an effective mechanism applied to gamified concepts to efficiently engage users with context (see section 5.6.3). Challenges in immersive video applications can be efficiently integrated in the form of multiple answer questions integrated in UI text panels in the virtual scene requesting interaction with it (see section 5.2). Learning outcomes can be achieved in case of integrating challenges related to the captured Cultural Heritage POIs in the 360-degree video scenes and involve exploration of the scene to reveal clues.

Benefit

Through constantly having to address challenges in an immersive video experience the viewers are better engaged with the context. Integrating a challenge mechanism in the design of immersive video applications adds a form of interaction with the virtual environment and the gives the users a mission they have to accomplish keeping them motivated.

Examples

In the Rethymno virtual tour the users were introduced with multiple answer questions they had to address by selecting the correct UI text panel element (see section 5.3.3). The introduction of such a mechanism allowed gaze-based interaction with virtual elements of the scene while kept the users motivated. The users were engaged with the context of the video representations through the textual information presented in the form of challenges.

DG10: Users should be notified about their achievements on addressing the challenges through visual information.

Motivation

Feedback mechanisms informing the users about their progress in the story, keeps them motivated and empowers them. This can be effectively achieved through the integration of visual graphic elements placed in the virtual scene with dynamically updated text (see sections 5.3.3 and 5.6.3).

Benefit

Providing constantly information to the users about their progress in a virtual experience increases the sense of engagement, while enhancing the overall immersive video experience.

Examples

A graphic UI visualization of the water collected has been presented at each immersive video scene, updated after each question challenges had been addressed keeping users informed about their progress (see section 5.3.3).

DG11: The design of challenges should follow a level-up approach informing the users through scoring visual mechanisms.

Motivation

Gamified design should be applied for increasing users' engagement with the virtual tour by incorporating activities that can be scored and level up (see section 5.2). Those activities introduced should be accompanied by adequate mechanisms for score visualization and level indication (see section 5.6.2.3).

Benefit

Scoring mechanism visualization and the assignment of badges to the users leads to their empowerment, sense of ownership and control of the experience.

Examples

The water collector indicator UI element was continuously informing the users on their level of completion in reaching their target (see section 5.3.3).

In general, according to the use case scenario: whether a relaxed paced virtual storytelling cultural tour is aimed, a gamified fast paced experience or and immersive educational experience the design techniques should be carefully selected based on their applicability and pros and cons.

5.8 Summary

The study presented in this chapter attempted to introduce a set of design tasks and techniques that should be considered at the experiential and interactive layers of the design process of creating 360-degree immersive video applications in order to provide engaging experiences. Those design aspects were considered in the creation of a testbed application of a virtual tour in the historical city of Rethymno, Greece. The Cultural Heritage virtual testbed application has been subjected to lab-studies involving real users allowing the evaluation of the proposed techniques. The results of the study led to the definition of a set of design guidelines suggested for the creation of immersive video interactive applications.

The evaluation results indicated that the methodology followed for the design of the 360-degree immersive video Rethymno virtual tour led to high level of engagement perceived by the participants. The immersion level was also satisfying with participants feeling comfortable throughout the experience that combined two moderate motion techniques, including 360-degree video captured with locomotion and teleportation, showing preference to teleportation. The integrated mechanisms for supporting navigation in the 360-degree virtual scenes and identifying POIs were significantly more efficient comparing to absence of navigation support. The first technique was based on the use of a human actor creating eye-contact with the subjects/participants to motivate them to look at the same direction with them, while the second was based on the use of graphic UI vectors pointing towards a POI.

A gamified design was also followed with the aim to engage the users’ further with the historical virtual tour experience and provide enhanced interaction with the video-based virtual scene. The tour introduced the mission of visiting the preserved fountains of

Rethymno to collect water, experiencing in a way the citizen daily activities of that period of time. In each scene of the tour a fountain was visited, and participants were presented with a challenge in the form of multiple answer questions that assigned participants with points in the form of liters of collected water. The participants were learning about the history of the city in a fun and entertaining way even in the cases they answered a question incorrectly. The proposed design methodology for 360-degree immersive video experiences offers a new approach for delivering informative and entertaining virtual tours.

Moreover, the second phase studies (see next Chapter 6) explore additional design methods and techniques that could be followed in 360-degree immersive video UI design such as the use of cognitive UI map visualizations for 360-degree in-scene navigation, task time and progress indicators. Different UI design approaches for VR should are also investigated on their pertinence in the case of 360-degree immersive video. The proposed techniques are evaluated in the next phase also evaluating usability by isolating the assessment of each design mechanism and performing further comparative studies. Due to the need for multiple scenes creation in order to perform comparative usability studies for different UI design approaches followed and elements integrated, it was not feasible to include this in the design of P1. This is considered therefore in the design and evaluation of the next prototype (see section 6.2).

Chapter 6

6 Second phase studies

This chapter provides a detailed description of the second phase studies. The chapter starts by outlining the objectives of the study and the research questions that are addressed. It continues with the presentation and justification of the iVID-based methodology that has been followed for the design and development of the 360-degree immersive video prototype that has been used in this study. It presents the experimental setting and continues with the presentation of the data output of the study. The chapter closes with the analysis and interpretation of the data collected, drawing conclusions that led to the formation of a (complementary to the first phase) set of design guidelines.

6.1 Aims of the study

The scope of the second phase study of this PhD research is subject to user evaluation of a set of different gamified, UI and actor's role design approaches usually followed in the games and VR interfaces design area to extract assumptions on their applicability and usability for the case of 360-video based immersive experience. This study is complementary to the first phase study (described in Chapter 5) focusing on design aspects that have not been integrated and evaluated systematically with the previous prototype. The second prototype design is based on methods defined following the iVID taxonomy for the experience and interactive layers, aiming at collecting data and deriving design guidelines for the actor's role design, the UI design and the gamified design aspects. The part of the iVID taxonomies this study focuses on is depicted in Figure 6. 1.

Those guidelines focus around:

- the role of human actors in engaging the user with the context, in gamified scenarios and guiding the user around POIs in the 360-degree scenes;
- the use of graphic UI elements for interaction and navigation support;
- the UI design approach;
- the integration of gamified tasks; and
- the provision of information about the context captured or the story through UI elements.

More specifically, this study tries to retain or reject the following hypothesis:

H01: The experimented gamified design techniques effectively engage the users of 360-degree immersive video applications.

H02: The diegetic UI design method is more efficient in the case of 360-degree immersive video applications.

H03: The use of human actors can effectively assist navigation tasks in 360-degree immersive video applications.

This final study contributes to the evaluation of the overall methodological design framework developed for the case of immersive video solutions, the iVID framework (see Section 4.9). The interpretation of this study results led to the definition of a new set of design guidelines which are presented at section 6.7 and address the final objective of this project (see Section 1.1) The instances of the second prototype were implemented by following the iVID process and incorporating the elements of design and techniques identified at each stage. Next section presents the way iVID has been used to guide the definition of design methods for the development of P2.

The following sections provide a detailed description of the prototype implementation and the methods designed for data collection concluding with the analysis of the studies' outcomes.

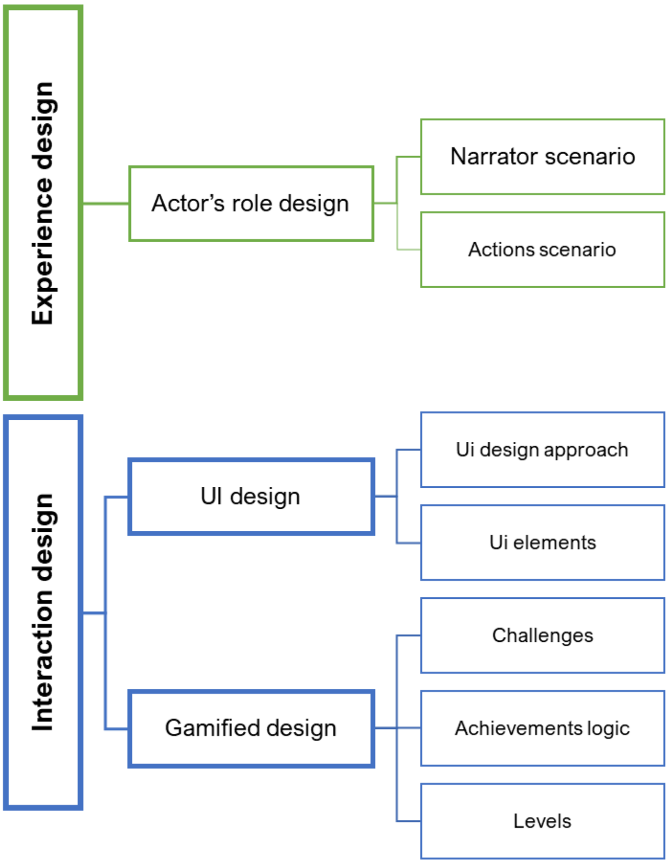


Figure 6. 1: Taxonomy of design aspects in experiential and interaction design layers addressed in the design of P2.

6.2 iVID-based methodological design for P2

For the second phase studies purposes, a different interactive 360-degree video-based virtual application has been developed for Oculus Rift VR headsets. This application consists of two instances. The first focuses on the application and evaluation of UI design methods while the second on actor's role design methods and different gamified design methods.

- P2-1 – UI design methods

The first instance consists of eight mini-game scenes taking place at four areas of the Historical centre of Rethymno where the user must perform a complex task of spotting three ancient vase 3D objects in the 360-degree scene. At each of the scenes visited the user is provided with different UI approaches and combination of UI elements aiming to assist the task completion.

- P2-2 – Gamified design and actor's role design

The second instance consists of four scenes that follow different actor' role design methods subjected to comparative evaluation studies with other techniques incorporating graphic elements aiming at motivating the user to interact with the environment. There is also another scene at the end following a different gamified design approach compared to the first instance.

Stage 1. Requirements analysis

The general design requirements have been adapted to address the needs of P2 design and listed below.

Dr1. Create a new form of game-based 360-degree video immersive prototype applications.

Dr2. Integrate efficient and comfortable UI design approaches to support interactivity with the VE and game tasks accomplishment.

Dr3. Use effective mechanisms and design approaches so as to not break immersion.

Dr4. Apply efficient narration approaches that engage the viewer with the context;

Dr5. Integrate effective and efficient mechanisms to guide the user around the 360-degree video scenes for spotting areas of interest;

Dr6. Use effective gamified design approaches applicable for the case of 360-degree immersive video scenes exploration.

Stage 2. Experience design

The taxonomy at the experiential design layer provided by iVID has been used to define design methods integrated in P2 instances and subjected to user evaluation.

Actor's role design methods: The method for using a human actor performing as a narrator has been selected and applied also in the second instance of P2 (P2 scene 1 same as P1 scene 1) to be compared to the use of textual information panels displaying the narration script (P2 new scene 2). Scenes 4 and 5 of P2 are also taken from P1 to allow the isolation and rigorous comparison of methods that can motivate users to turn and look at a certain direction, either through the human contact technique or through graphic elements. This complementary to P1 evaluation of those approaches in P2 aims to provide further insights on the efficiency of those techniques though a more focused comparative evaluation.

Stage 3. Story design

The user journey and video scripts specification are produced at this step following a similar approach as for P1. The same video resources of P1 have been also used in P2. For the implementation of each scene four short, one-minute long, 360-degree videos capturing different areas at the historical centre of the city of Rethymno were used. Therefore, the users experience a different area of the city in each scene overcoming the issue of becoming familiar with the experimental environment they must explore in order to discover the POIs. The difference is that P2 does not follow a complex storytelling design process as in P1.

Stage 4. Interaction design

UI design methods: In P1 different UI design approaches have been followed in each of the scenes.

- scenes (1-4) is based on the diegetic approach (see Section 4.8);
- scenes (5-8) is based on the non-diegetic approach (see Section 4.8).

That specific approach in the design of P2-1 was followed to facilitate a comparative study and evaluation of the integrated UI design methods by gathering and analysing data related to user performance, preference, and satisfaction.

Gamified design methods: The gamified task the users are requested to perform in P2-1 is to spot and collect three different ancient vases placed in the 360-degree scene. This task represents the challenge the users need to address formed in three levels (same as the number of objects to be spotted). Each of the eight scenes of P2-1 incorporates a different combination of gamified UI elements for: providing progress feedback to users; navigation assistance and time constraints. Those elements use form an achievements presentation logic.

The gamified UI elements used for the prototype design are:

- a radar map representation marking the position of the elements in the scene and the user’s viewshed;
- a timer element counting down in 60 seconds the time available to accomplish the task (of collecting the available objects); and
- a progress feedback element that is updated each time an object collection is completed, indicating how many objects have been collected and the remaining objects to be collected.

For each of those three elements, there are two different representations used to allow the design of non-diegetic and diegetic UI approaches. One that was attached to the camera and one that was intended to be placed as a panel object at a static position in the scene.

A different gamified design method has been selected and applied in P2-2 Scene 3 where the user is presented with the challenge to spot a specific area depicted in the video scene according to a description given. Three potential areas are marked in the video scene with a black circle graphical element. Feedback on the user achievement is given by colouring the circle green if correct or red if it is a wrong selection.

Stage 5. Scenes design

At this stage the mapping of UI approaches and elements that should be applied in each of the video scenes is performed followed by the definition of the graphic elements used for the interface design of P2.

As mentioned in the beginning of the section, in each of the scenes a different UI design approach has been followed to allow comparative evaluation and usability assessment of each combination of design elements integrated in 360-degree immersive video applications. Table 6. 1 below shows the elements integrated in each scene of P2-1 and indicates where diegetic or non-diegetic design has been applied.

Therefore, in each scene the users had to follow the panel instructions and then perform the requested task of spotting the objects as fast as possible supported by the available UI elements. The radar map purpose was to assist them in spotting the objects by depicting their position according to the user's view. The progress element was intended to inform users about how many objects remain to be found and the timer to add a time constraint with the aim to motivate them to be quicker.

	Diegetic				Non-diegetic			
	Sc. #1	Sc. #2	Sc. #3	Sc. #4	Sc. #5	Sc. #6	Sc. #7	Sc. #8
Radar map	✓	✓	✓		✓	✓	✓	
Timer	✓		✓	✓	✓		✓	✓
Progress bar	✓	✓		✓	✓	✓		✓

Table 6. 1: Mapping of UI elements integrated in each scene

A set of specific design approaches were followed for the design of each interface element that has been integrated in P2-1 and P2.2 with the aim study their effect in improving usability and increasing the level of interaction in 360-degree immersive video. Those design approaches were based on the first phase study's outcomes (see Chapter 5, section 5.7), recommendations from user experience experts' following an iterative process of developing the prototypes (pre-experimentation/validation phase), as well as suggestions found by the literature review analysis.

The following list provides an analysis for the design of the interface elements integrated in the second prototype:

I. Text panels

The text panels were integrated in a specific part of the 360-degree immersive video in a position that appears straight in front of the user when entering a scene (assuming a user is facing the PC straight when wearing the HMD – no change in device accelerometer). The position of the text panels is fixed in the scene and does not follow the user's view so as not to be distracting. The text splits in short chunks and formatted for better legibility. The panels are placed next to the POIs (e.g. the fountains of the Ottoman period depicted in the scenes) to avoid overlapping and hiding them (see Figure 6. 11 and Figure 6. 12).

II. Objects in the environment

The 3D representations of ancient vases are placed inside the 360-degree spherical environment in static positions and in areas of the video scene captured as close as possible to a position they would be expected to be found in real life (for example the vases are placed close to a pavement near the fountain that the 360-degree video is captured). The conveyed interaction with object was marked with a halo effect and a gaze-based interaction loader (see Figure 6. 4).

III. Diegetic UI elements

The diegetic approach design of UI is formed by representations visualised in the 3D space that exist in the fictional game world. Therefore, the UI elements that have been used match the video environment, such as a street clock for a timer and map board integrated in the scene for a radar map (see Figure 6. 5).

IV. Non-diegetic UI elements

The non-diegetic UI elements had to be as less distracting a possible and comfortable to view while not hiding large or important parts of the video scene. Therefore, transparency has been added to those elements and they appear as small as possible while maintaining readability and avoiding eye strain. For these reasons, those UI elements are at the centre of the on-top curved environmental part of the camera’s viewshed covering approximately the 1/9 of the view (see Figure 6. 7).

6.3 Prototype development

The prototype of the second phase studies is a 360-video based Oculus VR application that was developed following the architectural design concept of the iVID Stage 6 built with Unity Game Engine (Unity, 2019).

The following two sections offer a more detailed description of the two instances of P2 that serve as research instruments of the second phase study.

6.3.1 First instance of P2 (P2-1)

The first instance of the second phase study prototype (P2-1) starts with a menu that enables the selection and running of one of the eight different scenes. The menu is designed in curved form to target Headset display for Oculus VR and allows gaze-based interaction and selection of its' elements (as shown in Figure 6. 2).

Figure 6. 2: Curved UI Menu for P2-1

By entering each scene, the users are presented with some information about the area in the form of text panels graphically represented as a piece of papyrus as seen in Figure 6. 3 below. The text panels are integrated in the environment accompanied by a "next" button leading to the forthcoming text panel that presents the task to be accomplished.

You are at the area of the Archaeological Museum, in front of the main gate of the Fortezza fortress.

Figure 6. 3: Text Panel displaying historical information for the area when entering a scene

The task the users are requested to perform is to spot and collect three different ancient vases placed in the scene by looking around using their gaze. When users focus on a specific object a circled blue loader graphic element and a halo effect is triggered and after a few seconds the object disappears indicating that is has been collected (as shown in Figure 6. 4).

Figure 6. 4: Object collection indication with loader and orange halo effect

Two collections of three different 3D ancient vase representations are used and placed in the 360-degree environment at different positions in each of the scenes. The objects to be collected are of different colouring and appearance and in some cases, they are more obviously distinguished, while in others they are blending with the background making it a bit more difficult to spot. At each scene, there are three objects of the same collection.

The radar map, timer and progress feedback UI elements have been integrated in each of the scenes either in diegetic or non-diegetic form following the specification defined at Stage 5.

The radar map though had two different representations for the diegetic approach, one with a dark background and one where the background was a top-down scene representation captured from Google Maps, as depicted in the figures that follow (see Figure 6. 5, Figure 6. 6, Figure 6. 7). Those two different representations were used for assessing their efficiency and user's acceptance and preference.

Figure 6. 5: Scene 1 UI diegetic elements, radar map with on-top view, progress feedback in the form of a 3D chest, timer in the form of a street clock

Figure 6. 6: Scene 2 UI diegetic elements, radar map with dark background, Ancient vase with representation blending with the background

Figure 6. 7: Scene 5 UI non-diegetic elements, progress feedback, timer, radar map

6.3.2 Second instance of P2 (P2-2)

The second instance of the prototype consists of five different scenes serving complementary evaluation goals to the first one. The objective of the study using this prototype focuses on the evaluation of the use of human actors that played specific roles in the scenes aiming at motivating the user to interact with the environment and engage them further with the context. The same approach used in the first prototype has been followed in the menu design targeting gaze-based interaction as depicted in Figure 6. 8.

Figure 6. 8: Curved UI Menu for P2-2

The first two scenes of P2-2 are formed to serve storytelling experiences that involve human actors or text displays in 360 video scenes respectively. Scene 1 of P2-2 captures a lady narrator introducing the user to the history of the city, while on her left side a panel of the city’s on-top view is included (Figure 6. 9(a)). This scene allows a comparative evaluation with scene 2, where the storytelling experience is based on text panels with short, one-paragraph information appearing in linear flow after the user selects the “next” button (as shown in Figure 6. 9(b)).


During the 17th century, after an especially long war (1645-1669) between Venice and the Ottoman Empire, Crete became an Ottoman Island, until the late 19th century, when the island became autonomous (1898), only to be annexed to the Greek state a few years later (1913).

(a) *(b)*

Figure 6. 9: P2-2 Scenes 1 and 2 storytelling with human as narrator and with text panels.

Scene 3 is designed to provide an alternative way of interacting with video scenes. The user is requested to identify which of the areas in the scene (within the video scene content) marked with black circle graphics are referred to the Ottoman period. In case the circle selected is the one that identifies correctly the object related to the Ottoman period, the circle turns green (see Figure 6. 10), while in the opposite case the circle turns red. That is also the only way of providing feedback to the users about their actions, while there are no other elements of support such as navigation, or progress indicators.

Figure 6. 10: Scene 3 of P2-2, spotting areas in the video scene with minimum UI support.

Scenes 4 and 5 are also taken form the first phase prototype experience to allow the isolation and rigorous comparison of the elements that motivate users to turn and look at a certain direction, either through the human contact technique or through graphic elements. In scene 4 the users are facing a human actor looking directly at them. The actor turns after a few seconds and looks at the area of the historical fountain the users are expected to look, with the aim of engaging the user to mimic their movement and follow accordingly (as shown in Figure 6. 11). In contrary, scene 5 uses graphic arrows instead of the human actor that appear in the scene pointing the direction of the fountain triggering the users to turn towards the area they are pointing (as shown in Figure 6. 12).

This fountain was erected in 1863 by Kasim Bey, son of Yunus Aga.
The Turkish inscription in Arabic reads: 'You who drink water or take water from this fountain, know that this is not enough: beg mercy on my soul and pray for the love of God'.

Figure 6. 11: Scene 4 of P2-2 with human actor looking at the area of interest

This fountain was originally erected in 1863 by Yunus Aga's son, Ethem Bey, and consists of a large plinth, four recesses crowned by low arches, and an inscription with a fine carving.

Figure 6. 12: Scene 5 of P2-2 with graphic arrows pointing at the area of interest

6.3.3 Mechanisms for log data

In order to be able to perform a more holistic evaluation of the user experience using the second phase prototype, different logging mechanisms have been integrated in the scenes of each instance (P2-1 and P2-2) that collect quantitative data on user's performance. Therefore, for each scene of P2-1 data is being collected on user time spent for completing the requested task of spotting and collecting the 3D ancient vases. This data is written in a csv file while running the prototype application and after each task is completed, in the form of:

Scene No.| Time in seconds | Timestamp

In P2-2 instance logging mechanisms are integrated in scenes 3, 4 and 5. The same structure and methodology followed for the mechanisms integrated in P2-1 scenes is also applied in Scene 3 of P2-2, where the task to be complete is similar (spot the artefacts in the video scene). In scenes 4 and 5 of P2-2 the scope of the integration of the log mechanisms is to record the time it takes users to change their direction of view and spot the area of interest with the historical fountain based on the integrated, to "look-at", motivational design element (human actor gaze direction, or graphic arrows direction). In scene 4, two separate videos have been used to create the experience. The scene starts with the first video depicting a human actor looking at the user to simulate the effect of human contact in order to create empathy (see Figure 6. 13). At the end of the first video, the second video starts to play in a loop to allow time to the user to accomplish the task of looking towards the fountain motivated by the gaze direction of the human actor who now turns to look at the direction of the fountain. The time recorder starts when the second video starts to play for the first time (as it is programmed to loop). When the user turns towards the area of the artefact, the text panel providing historical information appears and the time recorded up to that moment is written in the csv file.

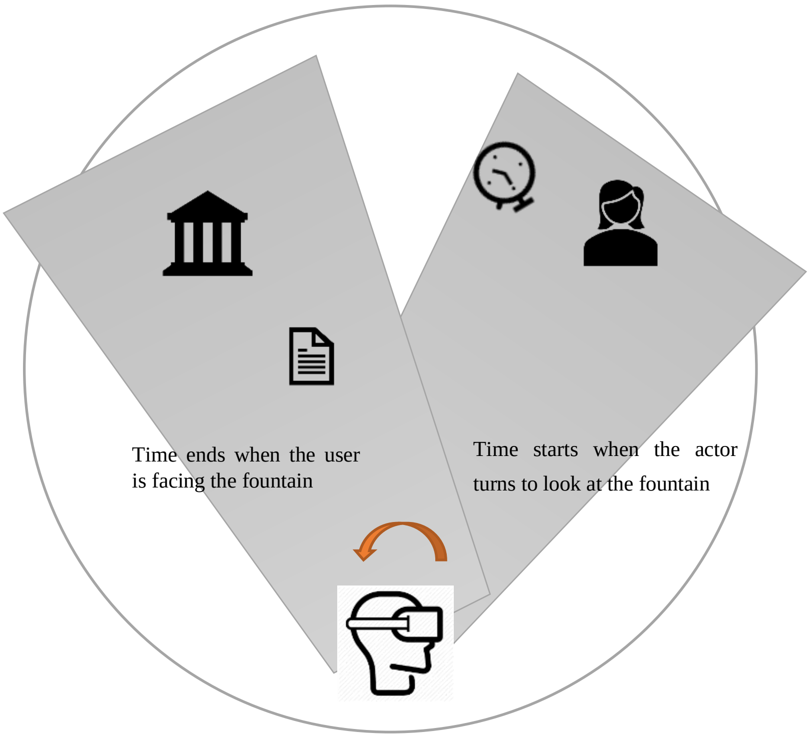


Figure 6. 13: Diagram depicting the process for logging time data in Scene 4 of P2-2

The same process was followed for Scene 5, the time recorder starts when the arrows appear in the scene and stops when the user looks towards to fountain. The arrows appear in the scene after a few seconds to match the time used in Scene 4 for the first video to play. The purpose of this delay is the compatibility in time records collected for both mechanisms.

Table 6. 2 below, depicts the different time log mechanisms that have been integrated in the second phase study prototypes. The different colours codes represent the different types of time log mechanisms that have been integrated in the prototype scenes.

	Time log mechanism							
	Sc. #1	Sc. #2	Sc. #3	Sc. #4	Sc. #5	Sc. #6	Sc. #7	Sc. #8
P2-1	✓ 🟨	✓ 🟨	✓ 🟨	✓ 🟨	✓ 🟨	✓ 🟨	✓ 🟨	✓ 🟨
P2-2			✓ 🟨	✓ 🟦	✓ 🟦			
Time log type colour code	Time it takes users to complete the requested task							🟨
	Time it takes users to change their direction of view							🟦

Table 6. 2:Table depicting the scenes of P2-1 and P2-1 different time log mechanisms that have been integrated

6.4 Study design

The second phase study has been designed to run in a controlled environment (lab at the University premises) recruiting people randomly in a voluntarily basis with different profiles (from different faculties) to assure diversity in technological background, age and gender (students, academics, technical and administrative staff). The study complied with the University of Westminster Code of Practice Governing the Ethical Conduct of Research 2017/18(see Appendix III). The study took place at the Mixed Reality (XR) lab, that fulfils the study requirements in terms of providing the necessary VR equipment in a controlled space. A PC with Oculus setup and the corresponding VR headset have been reserved and each session has been scheduled for approximately one hour per participant.

To collect the evaluation data for this study the following research instruments have been designed and used:

1) a questionnaire consisting of three parts:
    a. demographic and general questions with multiple answers;

b. a scene-specific set of questions with a 1-5 Likert scale (where 1= strongly agree, 5=strongly disagree) for collecting usability data related to the mechanism used and design approaches followed;

c. a set of questions related to immersion again with a 1-5 Likert scale based on the Immersive Experience Questionnaire (IEQ) by Jennett et al. (2008)

The questionnaire can be accessed in Appendix II.1

2) prototypes P2-1 and P2-2 that integrated logging mechanisms for collecting data on user performance (time to accomplish task in seconds).
3) note taking during conducting the test to collect qualitative information about the participants overall experience

The duration of each session has been planned to run for approximately 40-50 minutes and involved the participants in trying out the two VR prototype instances in the controlled environment using an Oculus VR headset available and replying to questions imposed by the researcher/moderator. One participant at a time interacted with the VR prototype instances. The people present at each session were the participant and the researcher. Each session started by informing the participant about the process and requesting participants to fill and sign the corresponding consent form about the data collected. Part A of the questionnaire was also requested to be filled a priori (see Appendix II.1.

The moderator was then helping the participant to put on the VR device and adjust it, so as to be comfortable, checking that user could easily read the text of the Oculus menu. The session started by running the first prototype instance P2-1 where the menu with the available stages appeared. The moderator asked the users to select a specific scene to run in order to control which order would be followed for each session. This action targeted a counterbalanced design of the study aiming to reduce the possibility that the order of running the scenes may adversely affect the results. For that reason, within the subjects design the participants in P2-1 tested the 8 scenes in different sequence such as 1-8, 8-1, 4-1 & 8-5, 5-8 & 4-1.

After each scene was complete, the participants were asked to return to the menu which provided a neutral environment for asking questions about the experience they just had. The moderator was sitting always near the participant to offer technical support in case it was requested. The moderator asked the specific questions designed for that scene (questionnaire part B – Appendix II.1) and marked down the user's answers, general comments, and feedback on a paper version of the questionnaire. In addition, observation notes have been collected throughout the time users interacted with the 360-degree immersive prototypes that formed qualitative data that has been collected during the study (see Figure 6. 14).

The same procedure was followed for the testing of the second instance of the prototype. When the trial of the prototype was complete, the participants were requested to take off the headset and fill in the final part of the questionnaire (part C - Appendix II.1) on their own. This part of the questionnaire collected data related to the participants overall sense of immersion.

6.5 Participants

The participants that took part at the second phase study were recruited through e-mail invitation circulated to the College of Design, Creative and Digital Industries staff members of the University of Westminster (including academic staff as well as technicians and admin staff) and through personal invitations sent to PhD students and Undergraduate students of Computer Science and Engineering Department. The targeted invitations were sent based on the persons interest in Digital Media and Immersive Technologies as indicated by their field of studies, or research.

The second phase studies took place in the XR lab for 10 days from Wednesday the 27th of March up to Monday the 8th of April 2019.

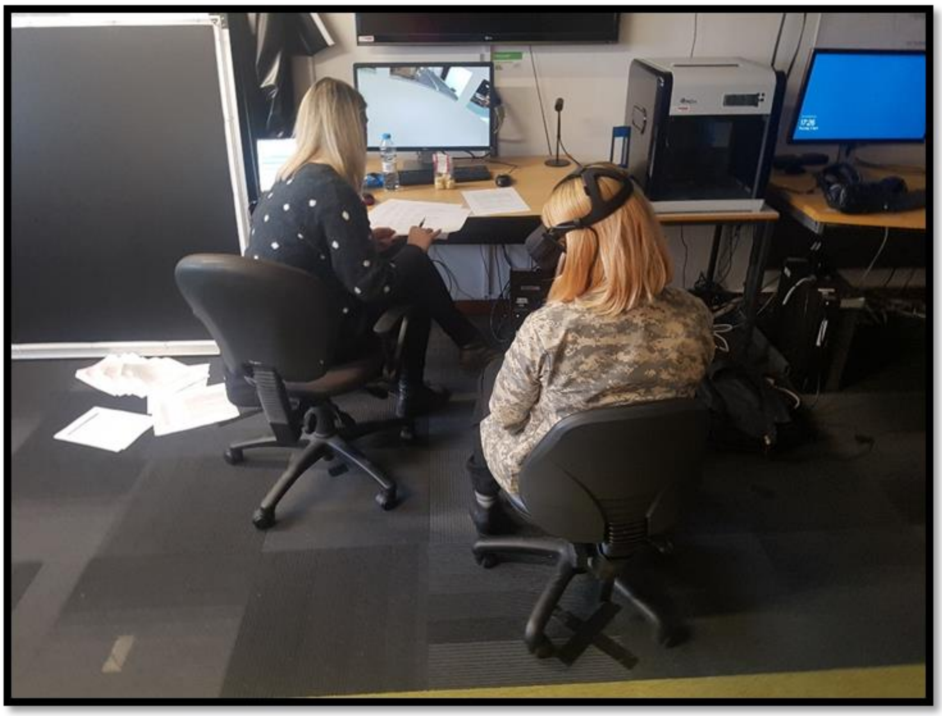
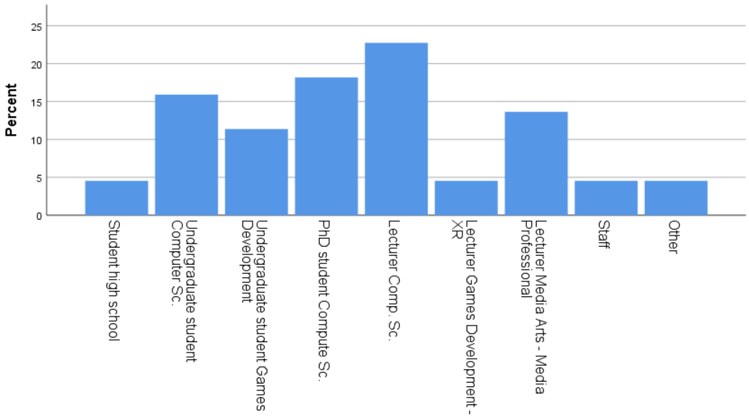
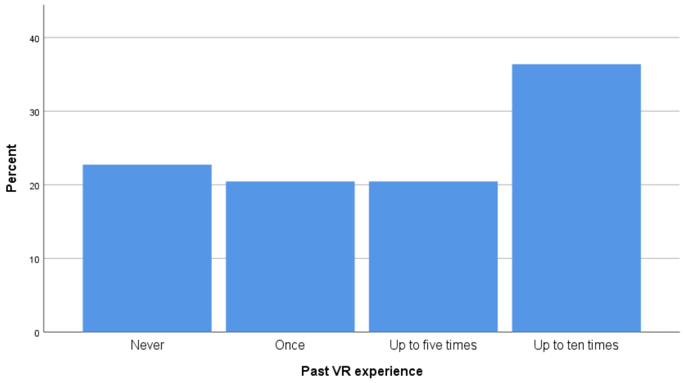


Figure 6. 14: Participant and moderator during the second phase studies at the XR lab

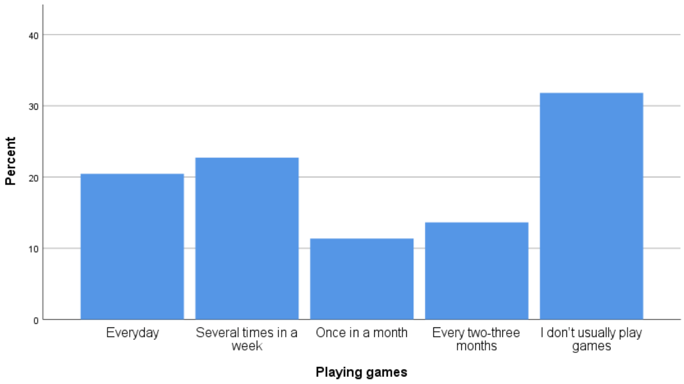
Forty four participants took part in the studies of which 30 male and 14 females with an age range of 16 to 62 years old and a mean of 34,2. The participants' background and VR and Games technologies literacy spanned with equal distributions, as depicted in the diagram below (see Figure 6. 15 a, b & c). Half of the participants had already previous experience with 360-degree video immersive applications.



(a)



(b)



(c)

Figure 6. 15: Histograms of participants background, VR experience in the past and gameplay habits

6.6 Data analysis

Through the evaluation process of the two instances of the second phase research instrument the data collected were through the questionnaire and log mechanisms integrated (as described before in section 6.3.3) and notes taken by the moderator during observation. The questionnaire and the log mechanisms generated quantitative data while the notes and feedback provided qualitative results.

The quantitative data collected through the questionnaires and the integrated logging mechanisms in the prototypes was organised and analysed with the use of SPSS. That leaded to the creation of 139 variables of scale, nominal and ordinal measure types that were defined and categorized as follows:

A. (11 variables – see Appendix Figure II. 6 SPSS rows 129-139) The integrated log mechanisms generated scale data (see Appendix Figure II. 15) capturing the time recorded in seconds for all scenes of prototype P2-1 and for scenes 3, 4 and

5 of P2-2. The time variable for P2-1 refers to the time each participant took to complete the assigned task of collecting the objects placed in the corresponding scene. The time variable for scene 3 of P2-2 refers to the time that each participant needed to complete the assigned task of spotting the correct object in the video. Time variable for scenes 4 and 5 refer to the time required for each participant to change its direction of view towards facing the fountain in the corresponding video motivated by the arrows and the human actor's gaze direction respectively.

B. (13 variables – see Appendix Figure II. 1 SPSS rows 1-13) Part A of the questionnaire generated scale data for the participants' age and nominal data for: their gender; previous immersive video experience and previous experience with several types of VR HMD devices (Oculus, Samsung Gear, HTC Vive, Google Cardboard, Other); and having tried the protype wearing glasses or not (see Appendix Figure II. 7).

C. (94 variables – see Appendix Figure II. 3, Appendix Figure II. 4, Appendix Figure II. 5, Appendix Figure II. 6 rows 35-128) Part B of the questionnaire generated ordinal (5 Likert-scale) and nominal (true/false statements) data (noted by the moderator during each test session) categorised per prototype-instance scene targeting the assessment of the user experience offered by the corresponding integrated design mechanisms and applied design methods (see Appendix Figure II. 9, Appendix Figure II. 10, Appendix Figure II. 11, Appendix Figure II. 12, Appendix Figure II. 13, Appendix Figure II. 14).

D. (21 variables – see Appendix Figure II. 2 SPSS rows 14-34) Part C of the questionnaire generated ordinal data for each of the 21 Likert type questions related to immersion, usability and engagement evaluation (see Appendix Figure II. 8).

The statistical processing of data has been done based on several methods such as non-parametric, descriptive, t-tests and chi-square tests based on their type (categorical or scale). The data analysis is performed in three steps:

- Step 1: Hypothesis formation: Two hypotheses are formed; a null (H0) and its alternative (H1). To accept the null hypothesis there should be no significant difference between the means of the variables observed.

- Step 2: Normality test: In order to decide if parametric or non-parametric tests should be performed, the data normality should be checked. Parametric tests can only be performed when data are normally distributed.

- Step 3: Analysis: according to the distribution of the data, the appropriate test methods are chosen concluding with the interpretation of their results and the acceptance or rejection of the null hypothesis.

The following sections provide a more thorough description of the analysis outcomes for each design element subjected to user evaluation.

6.6.1 UI design

The UI design approach in P2-1 and P2-2 has been evaluated through the analysis of quantitative data collected from log mechanisms and users answers to relative questions as also though qualitative data concerning user comments collected through note taking. This data provides values on measuring user performance affected by specific UI design methods and the appearance and functionality of UI elements integrated in different scenes of the prototypes (P2-1, P2-2).

6.6.1.1 Non-diegetic and Diegetic UI design

Quantitative data analysis

Following the completion of P2-1 testing phase the participants where asked, by the moderator, to state which of the two approaches of UI design, diegetic vs not diegetic, followed they found: most efficient; most comfortable; most satisfying; and which one allowed them to connect better with the environment (focusing on immersion sense evaluation). Those questions provided nominal data.

The hypothesis for this data analysis process are:

H0: There is no difference in user preference of Non-diegetic and diegetic UI design for 360-degree immersive video

μ participant preference of Non-diegetic UI design = μ participant preference of diegetic UI design

H1: There is difference in user preference of Non-diegetic and diegetic UI design for 360-degree immersive video

μ participant preference of Non-diegetic UI design ≠ μ participant preference of diegetic UI design

Where preference is related to user scores for satisfaction, efficiency, comfort and or sense of immersion.

Diagram in Figure 6. 16 provides the analysis of the user response to a set of questions that reflect their preference of the two design approaches. Based on this analysis it can be assumed that in terms of user satisfaction μ=66,67% of participants and efficiency μ=69,77% of participants preferred the Non-diegetic approach. Therefore, the Non-diegetic approach was more successful in satisfying those usability metrics.

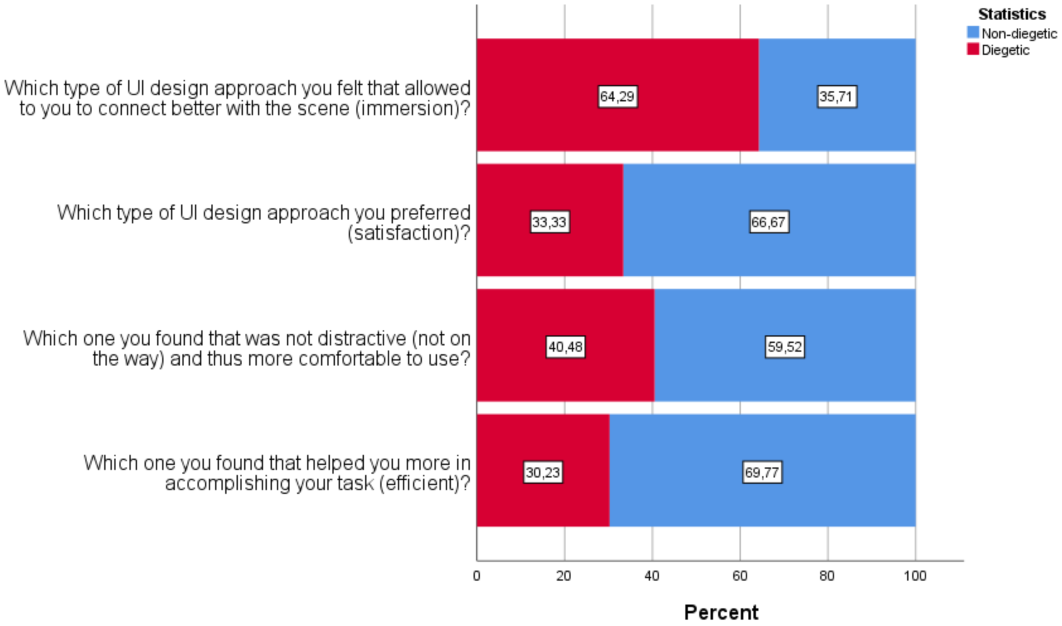
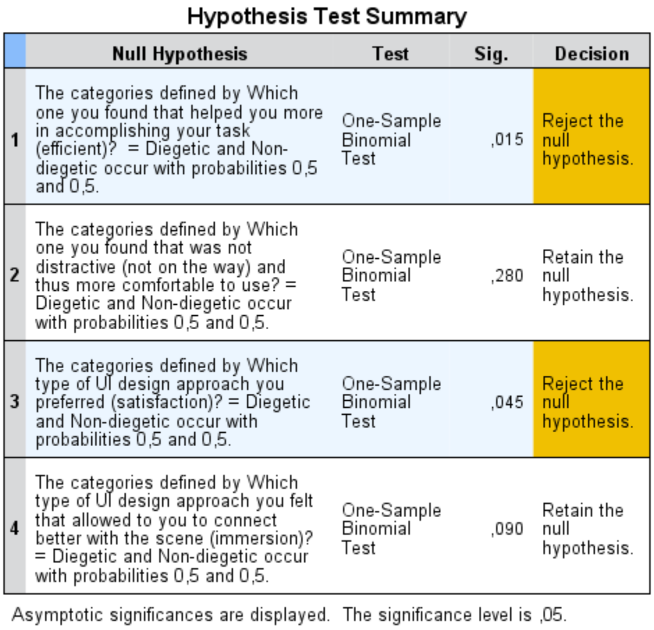


Figure 6. 16: Percent analysis of non-diegetic vs diegetic UI related data

No clear assumptions can be provided based on the data capturing the comfort of use between the two UI approaches, nor on the sense of immersion related to user's feeling of connection with the scene. To assess the hypothesis formed above, binomial one-sample tests were performed concluding that the means comparison (of nominal data) are not significant with p>0,05 (0,280 for comfort use and 0,090 for immersion) as shown in Figure 6. 17 (as extracted from the SPSS one-sample non-parametric analysis).



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories defined by Which one you found that helped you more in accomplishing your task (efficient)? = Diegetic and Non-diegetic occur with probabilities 0,5 and 0,5.	One-Sample Binomial Test	,015	Reject the null hypothesis.
2	The categories defined by Which one you found that was not distractive (not on the way) and thus more comfortable to use? = Diegetic and Non-diegetic occur with probabilities 0,5 and 0,5.	One-Sample Binomial Test	,280	Retain the null hypothesis.
3	The categories defined by Which type of UI design approach you preferred (satisfaction)? = Diegetic and Non-diegetic occur with probabilities 0,5 and 0,5.	One-Sample Binomial Test	,045	Reject the null hypothesis.
4	The categories defined by Which type of UI design approach you felt that allowed to you to connect better with the scene (immersion)? = Diegetic and Non-diegetic occur with probabilities 0,5 and 0,5.	One-Sample Binomial Test	,090	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 6. 17: Non-parametric analysis for data related to Non-diegetic vs Diegetic UI

The log mechanisms integrated in Scenes 1-8 of P2-1 provided scale data measuring the time in seconds the user needed to complete the assigned task of collecting three objects placed in each scene designed following different UI approaches (see section 6.2).

The hypothesis tested is:

H0: the time for collecting objects is not affected by the application of different UI design elements

time log scene1- 8 = time log scene1-8

H1: the time for collecting objects is affected by the application of different UI design elements

time log scene1-8 ≠ time log scene1-8

The normality of this data, generated by the user session logs for each of the P2-1 scenes, has been assessed by performing the Kolmogorov-Smirnov and Shapiro-Wilk test. The results of these tests are displayed in Table 6. 3 below. Provided that p<0,05 (for all scenes of P2-1) it is assumed that the data are not normally distributed.

Therefore, it is not possible to proceed with a parametric repeated measures comparative analysis such as ANOVA and a non-parametric equivalent is suggested.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
P2-1 Scene	Statistic	df	Sig.	Statistic	df	Sig.
Scene1	,155	44	,010	,856	44	,000
Scene2	,227	44	,000	,775	44	,000
Scene3	,178	44	,001	,904	44	,001
Scene4	,166	44	,004	,829	44	,000
Scene5	,137	44	,036	,777	44	,000
Scene6	,161	44	,006	,915	44	,003
Scene7	,167	44	,004	,808	44	,000
Scene8	,184	44	,001	,839	44	,000

Measure: time in seconds

Table 6. 3: Normality tests for P2-1 scenes time in seconds log data the user needed to collect the objects placed in each scene designed applying different UI approaches

The equivalent non-parametric test chosen is the Friedman's test and that does not include though interactions analysis. The nonparametric Friedman test results explored the differences among repeated measures on time participants spend collecting objects in all 8 scenes of P2-1 (df=7) and revealed a significant (p=0 <0,05) Chi-square value of 40.932 (see Table 6. 4). This points out that there is significant difference between the time data mean ranks corresponding to each scene and thus the UI design applied in the 360-degree immersive video affects user performance. The results indicate that the most efficient design approach followed in terms of user performance time is that of Scene6 with the smallest mean rank value of 2,98 and where the non-diegetic UI design approach has been followed (see Table 6. 1).

P2-1	**Mean Rank**
Scene1	5,61
Scene2	4,64
Scene3	4,59
Scene4	5,23
Scene5	3,86
Scene6	2,98
Scene7	3,82

Friedman Test statistics

N	44
Chi-Square	40,932
df	7
Asymp. Sig.	,000

Measure: time in seconds

Table 6. 4: Nonparametric Friedman test mean ranks and statistics for log time data of P2-1 scenes

A post hoc analysis has been performed for pairwise comparisons using Wilcoxon signed-rank test among the different scenes following Non-diegetic vs Diegetic UI design but having the same video scene and UI elements integrated (see Table 6. 5). From the Wilcoxon Signed Ranks pairwise comparison analysis it is evident that there is significant difference between Scene 5 – Scene 1 (p=0 <0,05) and Scene 6 – Scene 2 (p=0,013<0,05). Therefore, the analysis of time log data is in line with the results on user’s preference presented before indicating that the most acceptable and efficient UI design approach for the case of immersive video is the Non-diegetic.

Wilcoxon Signed Ranks Test statistics

P2-1	Z	Asymp. Sig. (2-tailed)
Scene5 - Scene1	-3,898	,000
Scene6 - Scene2	-2,486	,013
Scene7 - Scene3	-1,015	,310
Scene8 - Scene4	-,210	,834

Measure: time in seconds

Table 6. 5: Wilcoxon Signed Ranks pairwise analysis of log time data in seconds between P2-1 equivalent designed scenes of Non-Diegetic vs Diegetic UI.

Table 6. 6 below also provides the descriptive statistics analysis of the time data (collected by 44 participants) for each scene showing the corresponding mean values, standard deviation and variance. Scene 6 design (Non-diegetic with radar map-progress feedback) offered the best results on time performance but with no significant difference from Scene 5 (radar map, timer, progress feedback) (p=0,60>0,05) or Scene 7 (radar map, timer) where the Non-diegetic approach has been also followed based on the results of Wilcoxon Signed Ranks tests (Table 6. 7). The difference with Scene 8 (timer, progress feedback) is significant (p=0>0,05).

Descriptive Statistics

P2-1	N	Mean	Std. Deviation	Variance
Scene1	44	25,7964750	9,31242712	86,721
Scene2	44	25,7295998	13,17876413	173,680
Scene3	44	22,2233214	5,66051247	32,041
Scene4	44	24,8556418	9,03546291	81,640
Scene5	44	21,4728591	7,91223764	62,604
Scene6	44	20,1837707	7,11812841	50,668
Scene7	44	21,8523834	8,91520802	79,481
Scene8	44	27,4781318	12,76295287	162,893

Measure: time in seconds

Table 6. 6: Descriptive statistics for time log data in seconds for each P2-1 scene

Wilcoxon Signed Ranks Test statistics

P2-1	Z	Asymp. Sig. (2-tailed)
Scene5 - Scene6	-1,879b	,060
Scene7 - Scene6	-1,354[b]	,176
Scene8 - Scene6	-4,015[b]	,000

Measure: time in seconds

Table 6. 7: Wilcoxon Signed Ranks pairwise analysis of log time data in seconds between P2-1 Scene 6 and the other 3 Non-Diegetic design Scenes.

The hypothesis tested is:

H0: There is no correlation between user profile and their indicated preference on UI design approaches (diegetic or non-diegetic) in terms of: efficiency; comfort use; satisfaction; and feeling of being immersed

H1: There is correlation between user profile and their indicated preference on UI design approaches (diegetic or non-diegetic) in terms of: efficiency; comfort use; satisfaction; and feeling of being immersed

A crosstab analysis between the user's demographic and general profiling categorical data (type B) has been performed to evaluate the hypothesis. there is a correlation between user profile and their indicated preference on UI design approaches (diegetic or non-diegetic) in terms of efficiency, comfort use, satisfaction and feeling of being immersed based on their responses analysed.

As the data are non-parametric, chi-square analysis has been performed.

The chi-square tests of the analysis showed that there is no strong evidence of relationship (as p>0,05):

- between the users' gender and UI comfort use preference (Pearson Chi-square = 0,632, dF=1, p=0,426>0,05;
- between the users' background/profession and UI comfort use preference (Pearson Chi-square = 7,906, dF=8, p=0,443>0,05;
- between the users' experience in VR and UI comfort use preference (Pearson Chi-square = 01,906, dF=3, p=0,592>0,05;

- between the users' habits on playing games and UI comfort use preference (Pearson Chi-square = 2,935, dF=4, p=0,569>0,05;
- between the users' experience in VR and UI satisfaction (Pearson Chi-square = 3,344, dF=3, p=0,342>0,05;
- between the users' gender and UI satisfaction (Pearson Chi-square = 0,525, dF=1, p=0,469>0,05;
- between the users' habits on playing games and UI satisfaction (Pearson Chi-square = 2,459, dF=4, p=0,652>0,05;
- between the users' experience in 360 video and UI satisfaction (Pearson Chi-square = 0,429, dF=1, p=0,513>0,05;
- between the users' background/profession and UI satisfaction (Pearson Chi-square = 13,684, dF=8, p=0,090>0,05.

Therefore, the null hypothesis must be rejected and its alternative H1 is accepted.

Qualitative data analysis

Though the non-diegetic UI design approach was the most preferred in terms of satisfaction and efficiency (Figure 6. 17), that assumption that derives based on participants comments during their experience with the study prototypes is that these results were related to the task users had to perform in the scenes. There were some users that pointed out that for a more relaxed immersive experience they found the diegetic approach as the most appropriate, while the non-diegetic kept them focused on the task: "*I could explore the scenery more with the diegetic UI and I could come back to them when needed", "depends on the task my preference, for more relaxed - the diegetic, for focusing on the task the non-diegetic", "but for a more relaxed experience I would prefer the diegetic approach".* Therefore, it can be concluded that the selection of the most appropriate design technique relies on the project's objectives towards a more engaging gamified experience or a more relaxed storytelling one.

6.6.1.2 Radar map, Timer and Progress indicator

Quantitative data analysis

The radar map UI design element has been integrated in the 360-degree video scene in order to motivate and assist the users to navigate in the 360-degree environment and spot the POIs, such as the 3D ancient artefacts. Based on descriptive statistics analysis, the radar map proved to be a somewhat-moderately useful mechanism in both forms of diegetic and non-diegetic design (Figure 6. 18 and Table 6. 8). As the data were derived from the user answers to the part b of the questionnaire (1-5 Likert scale (where 1= strongly agree, 5=strongly disagree) were categorical and therefore not normally distributed. The nonparametric Friedman test has been selected to explore the differences among repeated measures on “The radar map was useful in spotting the elements in the scene” for the 6 scenes were it was used (df=5) revealing a non-significant (p=0,192 > 0,05) Chi-square value of 7.41 (see Table 6. 9). There is no significant difference therefore, between the usefulness of the radar map element in the different scenes integrated.

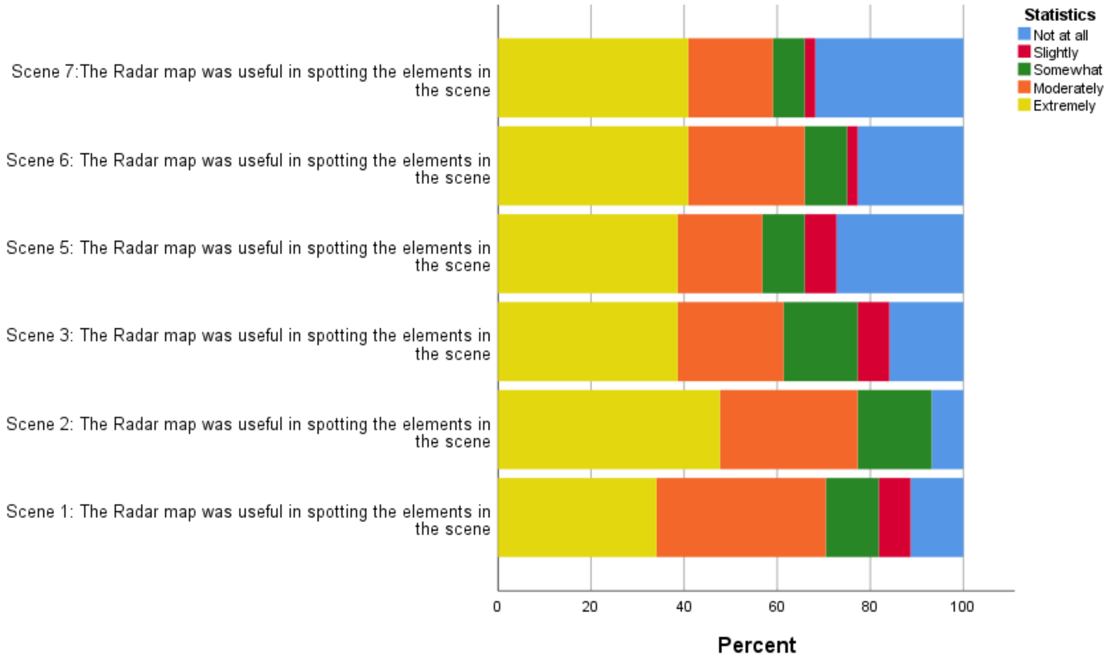


Figure 6. 18: Radar map element usefulness results

Descriptive Statistics

The Radar map was useful in spotting the elements in the scene	N	Mean	Std. Deviation	Minimum	Maximum
Scene1	44	3,75	1,314	1	5
Scene2	44	4,11	1,125	1	5
Scene3	44	3,61	1,466	1	5
Scene5	44	3,34	1,684	1	5
Scene6	44	3,59	1,589	1	5
Scene7	44	3,34	1,751	1	5

Table 6. 8: Radar map element usefulness descriptive statistics

Friedman Test statistics

N	44
Chi-Square	7,410
df	5
Asymp. Sig.	,192

Measure: usefulness

Table 6. 9: Nonparametric Friedman test statistics for radar map usefulness

The progress indicator appeared to be a less useful element and especially in Scenes 1&2, where the diegetic approach was followed, based on the quantitative results of categorical data analysis in percent per 1-5 option (see Figure 6. 19) and descriptive statistics (see Table 6. 1). The nonparametric Friedman test was applied to explore the differences among repeated measures on “The progress/feedback element was useful in spotting the elements in the scene” for the 6 scenes were it was used (df=5) revealing a significant (p=0 > 0,05) Chi-square value of 23.567 (see Table 6. 11). A post hoc analysis has been performed for pairwise comparisons using Wilcoxon signed-rank test among the different scenes following Non-diegetic vs Diegetic UI design but having the same video scene and UI elements integrated (see Table 6. 12). The Wilcoxon Signed Ranks pairwise comparison analysis revealed significant difference between Scene1 – Scene5 (p=0,01 <0,05) and Scene2 – Scene6 (p=0,022<0,05). The progress indicator element has been found more useful therefore in its non-diegetic form and specifically when accompanied by the radar map element (in Scene8 the radar map was not used).

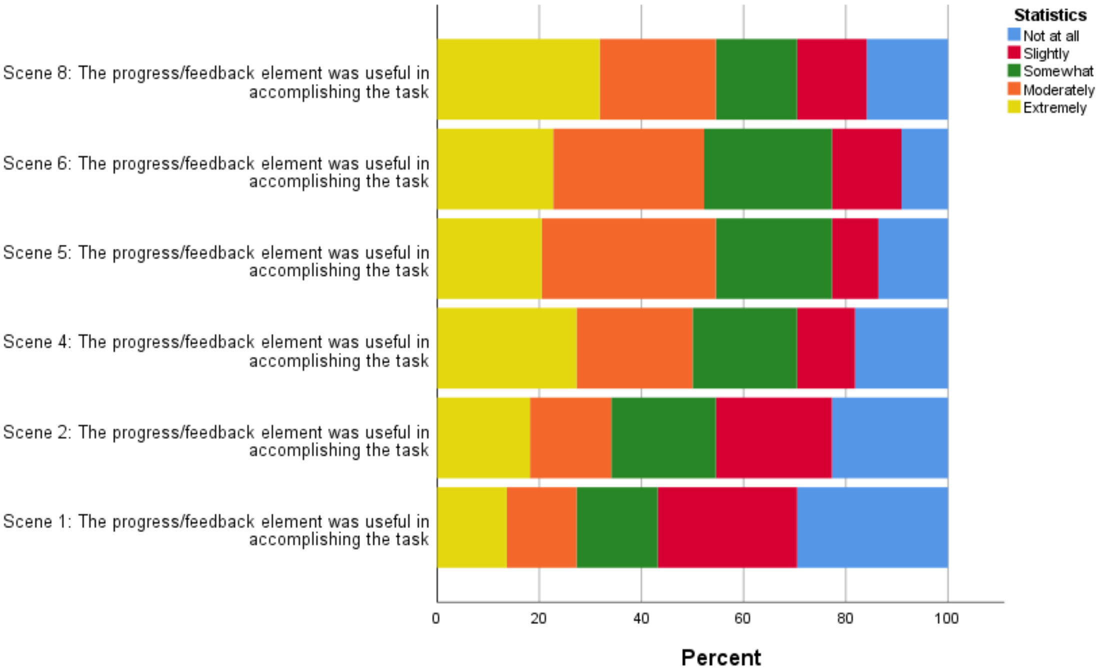


Figure 6. 19: Progress feedback element usefulness results

Descriptive Statistics

The progress/feedback element was useful in accomplishing the task	N	Mean	Std. Deviation	Minimum	Maximum
Scene1	44	2,55	1,405	1	5
Scene2	44	2,84	1,430	1	5
Scene4	44	3,30	1,456	1	5
Scene5	44	3,39	1,298	1	5
Scene6	44	3,43	1,246	1	5
Scene8	44	3,41	1,468	1	5

Table 6. 10: Progress/feedback element usefulness descriptive statistics

Friedman Test statistics

N	44
Chi-Square	23,567
df	5
Asymp. Sig.	,000

Measure: usefulness

Table 6. 11: Nonparametric Friedman test statistics for progress indicator usefulness

Wilcoxon Signed Ranks Test statistics

The progress/feedback element was useful in accomplishing the task	Z	Asymp. Sig. (2-tailed)
Scene1-Scene5	-3,234	,001
Scene2-Scene6	-2,287	,022
Scene4-Scene8	-,263	,792

Measure: usefulness

Table 6. 12: Wilcoxon Signed Ranks pairwise analysis of progress indicator usefulness between P2-1 equivalent designed scenes of Non-Diegetic vs Diegetic UI.

On the other side, the timer element was not that successful in keeping the users focused on the task and especially in the diegetic design form (Scenes 1, 3, 4,) as it can be observed by the results analysis (percent per 1-5 option) in Figure 6. 20 below and descriptive statistics in Table 6. 13 (mean values and std. deviation). The nonparametric Friedman test was applied to explore the differences among repeated measures on “The timer element was useful in spotting the elements in the scene” for the 6 scenes were it was used (df=5) revealing a significant (p=0 > 0,05) Chi-square value of 54.222 (see Table 6. 14). A post hoc analysis has been performed for pairwise comparisons using Wilcoxon signed-rank test (see Table 6. 15). The Wilcoxon Signed Ranks pairwise comparison analysis revealed significant difference between Scene1 – Scene5 (p=0<0,05) and Scene3 – Scene7 (p=0 <0,05) and Scene4-Scene8 (p=0 <0,05). The timer element has made the users more focused on the task in its non-diegetic form.

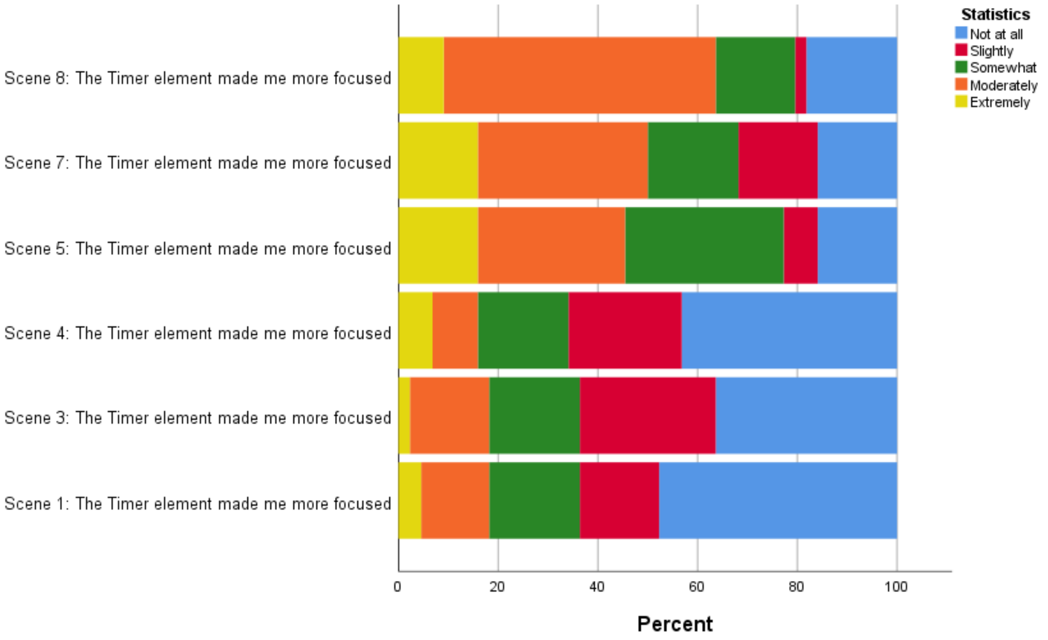


Figure 6. 20: Timer element contribution in keeping the users focused results

Descriptive Statistics

The Timer element made me more focused	N	Mean	Std. Deviation	Minimum	Maximum
Scene1	44	2,11	1,280	1	5
Scene3	44	2,20	1,173	1	5
Scene4	44	2,14	1,268	1	5
Scene5	44	3,23	1,273	1	5
Scene7	44	3,18	1,334	1	5
Scene8	44	3,34	1,256	1	5

Table 6. 13: Timer element usefulness descriptive statistics

Friedman Test statistics

N	44
Chi-Square	54,222
df	5
Asymp. Sig.	,000

Measure: usefulness

Table 6. 14: Nonparametric Friedman test statistics for timer usefulness

Wilcoxon Signed Ranks Test statistics

P2-1 The Timer element made me more focused	Z	Asymp. Sig. (2-tailed)
Scene1-Scene5	-3,741	,000
Scene3-Scene7	-3,597	,000
Scene4-Scene8	-3,812	,000

Measure: usefulness

Table 6. 15: Wilcoxon Signed Ranks pairwise analysis of timer usefulness between P2-1 equivalent designed scenes of Non-Diegetic vs Diegetic UI.

The UI elements were found in general useful for exploring the 360-degree scene and accomplishing the assigned tasks. This is supported also by the results analysis from the question "Did you feel like missing guidance of where to look, how many items you had to find" concerning Scene 3 of P2-2 where such elements were missing. The percent of answers by the users in this question are shown in the line diagram below (Figure 6. 21) revealing that most missed UI guidance in moderately-extremely levels.

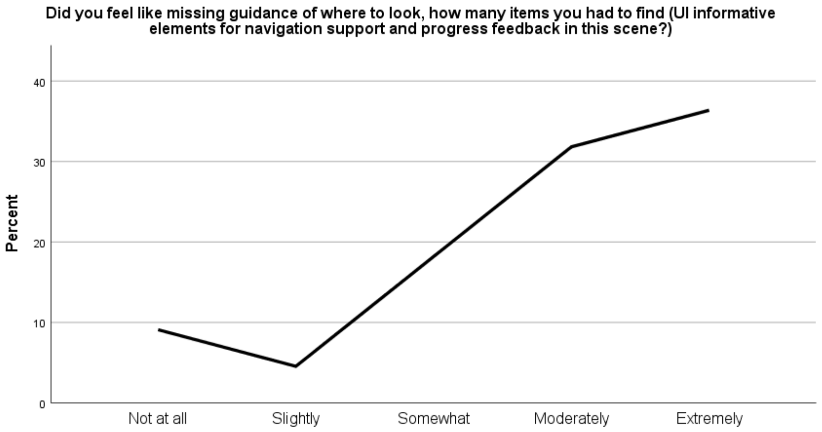


Figure 6. 21: Line diagram of Scene 3 P2-2 results on the importance of UI support

Non-diegetic UI elements - Qualitative data analysis

The non-diegetic UI elements are in the form of 2D panels with graphic representations attached to the camera. As those elements are always in the view of the user, their placement should be designed to ensure comfort use and legibility avoiding eye strain effects. Moreover, they should be designed with some transparency to avoid hiding completely parts of the background video scene.

In P2-1, the three UI non-diegetic elements (radar map, timer and progress indicator) were positioned in a grouped area at the top-centre of the camera view (Figure 6. 22).

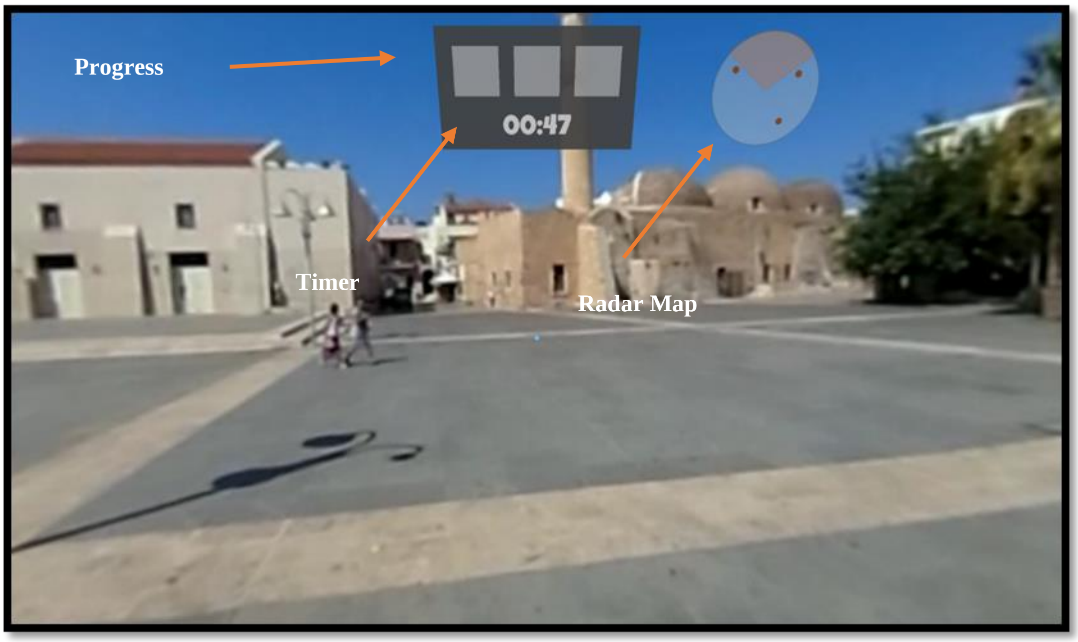


Figure 6. 22: Non-diegetic UI elements positioning and appearance

The analysis of the qualitative study output pointed out that for some users the radar map which appears on the top-right should be positioned closer to the centre of the view span as it caused eye strain. In addition, it was suggested that the UI area should be minimized as it was distracting the user’s attention from the scene. Some of the user comments after experiencing scenes 5-8 where the non-diegetic approach had been followed, are:

“*the progress indicator was too large, taking too much space*”;

“*the UI elements were too high, and I was not able to look at the objects*”;

“*the map should be placed better at the centre*”;

“*hard to notice the radar map*”;

“the radar map was a bit too high, hard to look that up”;

“*the radar map was a bit small*”;

“*the UI was taking less space as there were only two elements, so it was better*”.

In Scene 8 that followed a non-diegetic design for the UI with only the timer and progress indicator displayed, the users pointed out: *“I missed the map in that scene, a bit more difficult to spot the objects without it”.*

<u>Diegetic UI elements - Qualitative data analysis</u>

In Scenes 1-4 lots of the participants found the progress indicator element a bit distractive as they thought it was an object to collect due to its misleading appearance in the form of a chest (see Figure 6. 5). The participants though pointed out that its usefulness dependent on the number of objects they had to find as it was small, and the radar map also displayed that information as the dots disappeared after each corresponding object had been spotted. Therefore, a better representation should be considered to make clear the purpose of the element and distinguish from any other object placed in the scene.

Moreover, the most effective radar map representation was the one with the dark background as it made the POIs easier to spot due to colour contrast while the one with the on-top view Google map in the background added cognitive load to the users as it took time to interpret its purpose (Figure 6. 23).

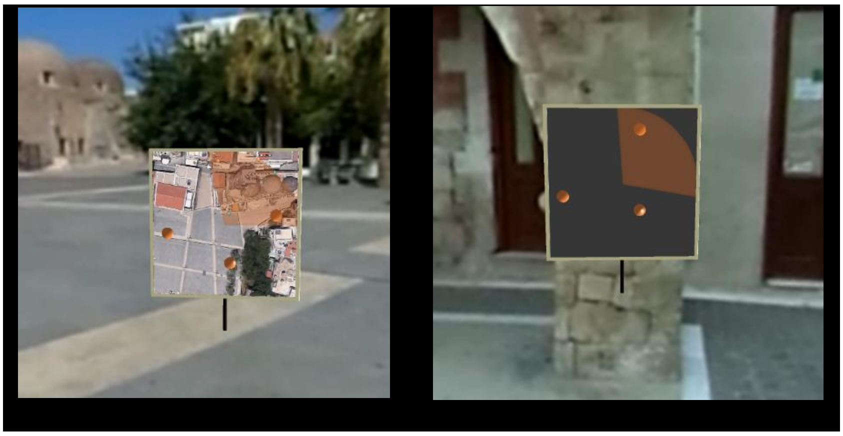


Figure 6. 23: Radar map diegetic visualisations

6.6.1.3 Instruction and information provision elements

In P2-1 and P2-2 historical information about the scenes and general instructions about the tasks is being provided in the form of graphic panel elements integrated in the scene. In most cases those panels are placed in front of the user's view displaying text in small chunks so as to be easily read. Interactive buttons to perform actions such as "back to menu", "play again" "start" and "next" have been placed just beneath the text panels.

There were several problems identified with the design and positioning of the text communication panels in the experience based on qualitative data analysis derived from observation notes and user comments. During the study it has been observed that users were straggling with reading the text panels being placed in front of their view due to the following reasons:

- the users were trying to avoid looking at the area of the interactive buttons as they were paced too close to the panels, the interaction through gaze was sensitive and as a result they were making choices accidentally;

- the panels appearing always in front of the users were dominant in a way they almost forced the user to interact with them and not continue the experience;

- the placement of the panels made the users feels they did not have complete control of their experience.

More specifically the participants have commented: *“the text panels were distractive and forced to look at those and not explore the scene, should be placed elsewhere in the scene and allow the user to find them on its own”, “the text panels with instructions made me quit, else I would stay longer”.*

Based on the evaluation of the user’s experience of the approach of providing textual communication in panels with limited chunks of text, it is recommended that those panels should be placed in different areas around the 360-degree environment allowing the user to explore the affordances of the environment more effectively. The interactive buttons should be placed possibly on the side of the panels and not directly in front of the user’s view eliminating the chance of error by selecting accidentally and preventing them from carefully reading the displayed information.

6.6.2 Gamified tasks design for interacting with the scene

There were two different challenges introduced to study gamified tasks design: a) in scenes (1-8) of P2-1 the user had to spot 3D objects integrated in the scene; and b) in scene 3 of P2-2 the user had to spot objects that were part of the video scene. The selected gamified task that the participants were introduced when experiencing each of the eight scenes of P2-1 was to try and spot three objects placed inside the 360-degree spherical environment and collect them through gaze-based selection as fast as they could. To support this activity the users were presented with UI elements such as the radar map, the timer and the progress feedback in different combinations (see Table 6. 1).

Quantitative data analysis

Provided the task was evaluated as very easy by most of the participants and in all scenes (as indicated in Table 6. 16), it can be assumed that its purpose to motivate users to explore the 360-scene was achieved, as they looked around in full degrees to spot the POIs. The mean value of the participants answers to the question “Did you feel that you have fully explored the scene?” was above 3 (neutral) in all scenes of P2-1 and Scene3 of P2-2 were gamified tasks were assigned to the users (see Table 6. 17).

Descriptive Statistics

Was is easy to spot the objects you were looking to find in the virtual scene?	N	Minimum	Maximum	Mean	Std. Deviation
Scene1	44	3	5	4,52	,698
Scene2	44	2	5	3,91	,936
Scene3	44	2	5	4,45	,791
Scene4	44	2	5	3,95	1,099
Scene5	44	1	5	4,48	,821
Scene6	44	2	5	4,52	,762
Scene7	44	2	5	4,43	,818
Scene8	44	1	5	3,75	1,081

Table 6. 16: Descriptive statistics for easiness of the gamified task

Descriptive Statistics

Did you feel you fully explored the 360-scene?	N	Minimum	Maximum	Mean	Std. Deviation
P2-1 Scene1	44	1	5	3,68	1,290
P2-1 Scene2	44	1	5	3,64	,990
P2-1 Scene3	44	1	5	3,86	1,133
P2-1 Scene4	44	1	5	3,91	1,053
P2-1 Scene5	44	1	5	3,45	1,247
P2-1 Scene6	44	1	5	3,55	1,130
P2-1 Scene7	44	1	5	3,55	1,170
P2-1 Scene8	44	1	5	3,73	1,128
P2-2 Scene3	44	1	5	3,43	1,043

Table 6. 17: Descriptive statistics for user’s perception of exploring the 360-degree scenes

Qualitative data analysis

A kind of different gamified task was also introduced in Scene 3 of P2-2 where the users had to spot areas in the video captured scene (and not 3D objects) marked with circle graphics (see Figure 6. 10). The users stated that they felt more connected with the environment where they had to find POIs that were part of the video scene compared to finding 3D objects integrated in the scene. A participant commented that “Searching for objects made me feel I had less control; I prefer the activity with the circled marked areas”.

Therefore, it can be assumed that the integration and design of gamified tasks in the scene to motivate users to look around and explore the 360-degree environment, are significant for providing the motive of interacting with the scene and fully exploring it. In addition, based on the results on the usefulness of the UI elements (see section 6.6.1.2) it can be concluded that the integration of a radar map element is necessary in directing the users to explore all the environment and find the elements of interest. The task should be also designed with demanding cognitive load making it more engaging.

6.6.3 The role of human actors

Human actors have been mostly used in P2-2 and more specifically in Scenes 1 and 4. In Scene 1, the lady actress was playing the role of the narrator saying a short story about the history of the city. This scene has been used to compare the role of the actor in storytelling providing historical information, with the use of text panels in Scene 2.

Another human actor has also been used for P2-2 Scene 4 to motivate the user to look towards the direction she was looking by creating a human contact effect at the beginning and then turning and looking at the POI of the scene. This design mechanism has been compared to the use of graphic vectors (arrows) for the same reason in P2-2 Scene 5.

Quantitative data analysis

The two following histograms display the normal distributions of the data collected through log mechanisms recording the time the users spent in seconds to change their direction and spot the fountain area in Scenes 5 & 4 of P2-2 (see Figure 6. 24). The normality of those data has been assessed by performing the Kolmogorov-Smirnov and Shapiro-Wilk test. The results of these tests for each of the scenes time data are displayed in the Table 6. 18 below. For Scene 4 p=0<0,05 and therefore data are not normally distributed while there is normal distribution of the Scene 5 data as p=0,054<0,05. From the Wilcoxon Signed Ranks pairwise comparison analysis it is evident that there is no significant difference between Scene 5 – Scene 4 (p=0,482 > 0,05) as provided in Table 6. 19. Therefore, no assumptions can be made based on the quantitative analysis on the most effective in time (faster) mechanism between the two in motivating users to change their direction. Both design mechanisms were though effective in motivating the user to turn in short time with Scene5 (graphic arrows) having a normal distribution and therefore indicating a more accurate approach. However, the vectors are quite dominant as a UI element integrated in the scene and therefore distractive. A single small arrow placed in the scene, pointing at the area of POIs, would be a more usable, still effective approach in motivating the user to change its direction.

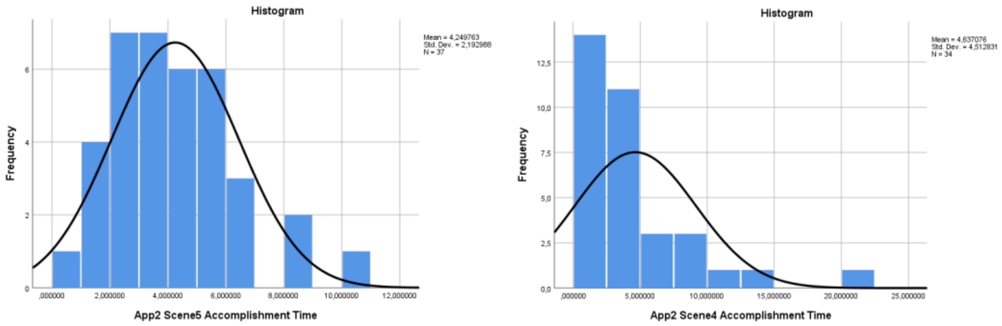


Figure 6. 24: Log data histograms on time spent in seconds to spot the fountain for P2-2 Scene 5 that used graphic arrows and for P2-2 Scene 4 with human contact technique

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
P2-2 Scene4	,226	29	,001	,778	29	,000
P2-2 Scene5	,150	29	,093	,930	29	,054

Measure: time in seconds

Table 6. 18: Normality tests for P2-2 Scenes 4&5 time in seconds log data

Wilcoxon Signed Ranks Test statistics

	Z	Asymp. Sig. (2-tailed)
P2-2 Scene5 - Scene4	-,703	,482

Measure: time in seconds

Table 6. 19: Wilcoxon Signed Ranks pairwise analysis of time between Scenes 4&5 of P2-2.

Qualitative data analysis

Participants expressed that the human actor used in Scene 1 of P2-2 as narrator adds to the sense of realness of the experience but displaying also text as information is also important as that would help them to absorb historical information more effectively. In case of creating more effective storytelling experiences, a combination is therefore suggested of narrators and textual information displayed on graphic panels in 360-

degree video. This could be an efficient method for any type of learner addressing the needs for the ones preferring visual as also auditory information. In order also to be more engaging, the narrators should be more vibrant using gestures relevant to their speech.

During the observation of the participants it has been identified that when human actors were included in the scene, they always capture the user attention who turned to follow them waiting for an indication of interaction. As the videos created included the person holding the camera, the human actors' presence was inevitable. In addition, the actor was too close to the user's view. In cases where the participant turned around and faced the human actor (see Figure 6. 1), they were naturally motivated to turn towards the direction the actor was looking/facing as they thought that there should be something interesting there that they have missed.

Figure 6. 25: Human actor recording the scene faced by the participants during the study, motivating them to lookup.

The capturing of humans in a 360-video experience should be considered and designed carefully to serve the roles of guiding and motivating the user through the story and the scenes POIs. The use of human actors provides a more natural and realistic approach for non-fast-paced gamified experiences where the performance time is not significant. Humans captured in video scene are an important element affecting the social influence factor that relates the provision of engaging experiences and should convey interaction with the experience POIs.

6.6.4 Overall Sense of Immersion evaluation

In order to evaluate the overall sense of immersion offered in the second prototype solution, as an interactive form of 360 video-based experiences for VR headsets, data has been collected through targeted 1-5 scaled questions (see Appendix II.1 and Appendix Figure II. 2) related to how users felt:

- in terms remaining focused on the activity, endurability (that relate to the sense of engagement);
- in terms of enjoyment, comfort and acceptability of use, sense of control (that relate to usability);
- in terms of sense of presence, time awareness, disconnection form the real world, and interaction with the virtual environment (that relate to immersion).

The results of the analysis per category of questions are visualised at the stacked histograms following.

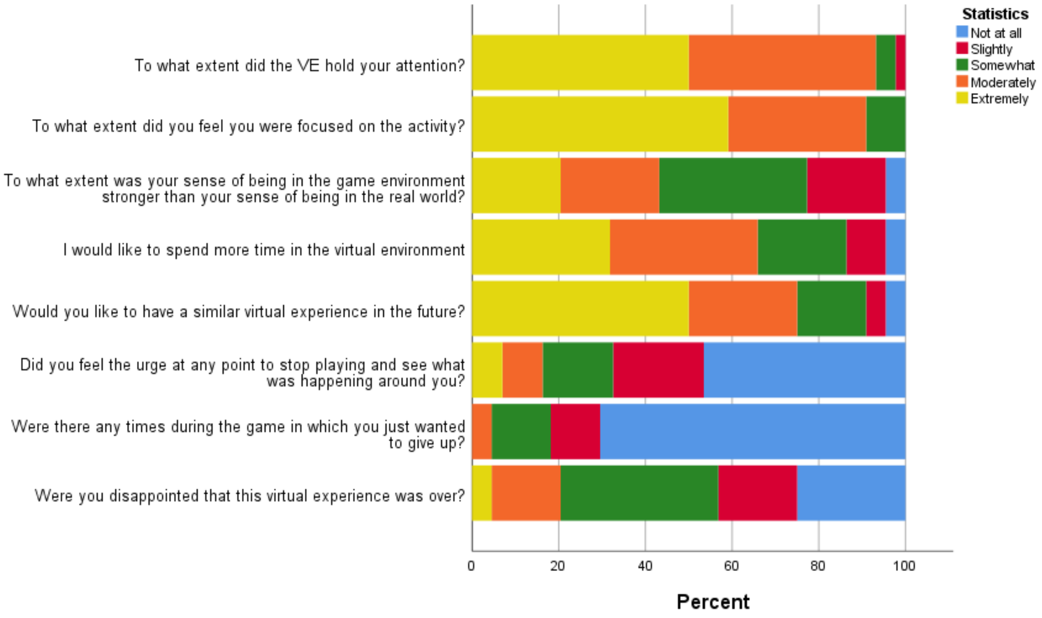


Figure 6. 26: Stacked histogram of participants feedback on engagement

From the results on engagement sense evaluation, as depicted in Figure 6. 26, it can be assumed that the experience provided, kept the users focused in the VR activity and it was something that most of them would like to try again in the future. The fact that user response on the question *"Were you disappointed that this virtual experience was over"* is more balanced, is expected as the overall experience lasted around one hour. On the opposite, experiencing something in VR for such a long duration without significant levels of discomfort is a good indication of the future potentials of that kind of medium.

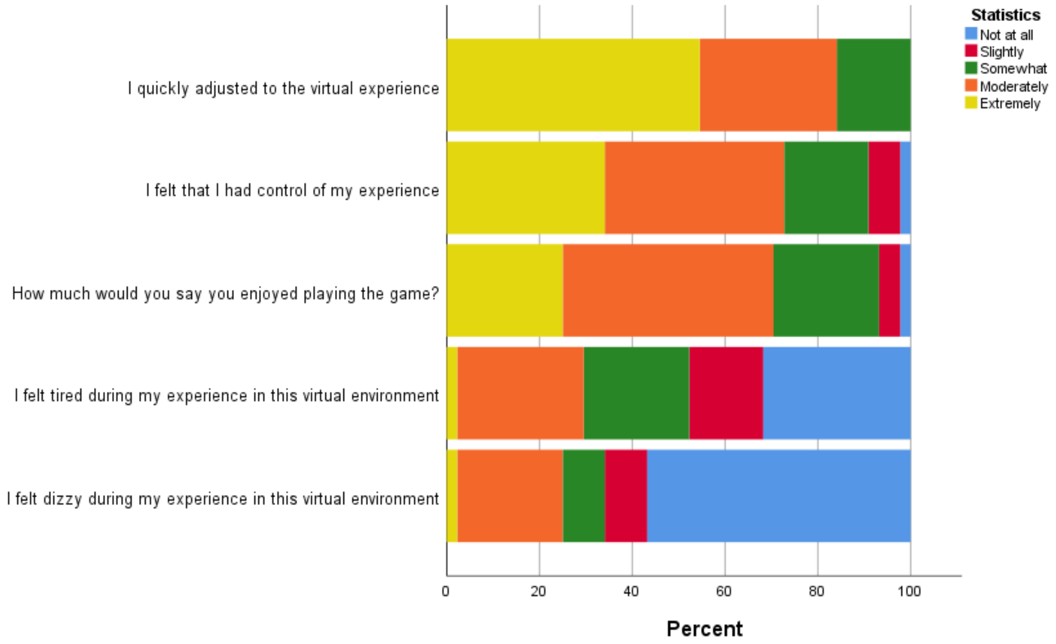


Figure 6. 27: Stacked histogram of participants feedback on usability

In terms of usability, as it can be observed through the statistics in Figure 6. 27, the participants become easily familiar with the experience maintaining the sense of control and enjoyment. No significant indication of motion sickness has been reported, but almost half of the participants felt somehow tired. Most of those participants that complained about some discomfort mentioned that this was due to the use of glasses (25% performed the test with glasses on) in combination with the headset making it hard in some cases to read the textual information even after adjusting the focus of the device. Ways to overcome these issues is suggested to be investigated through future studies.

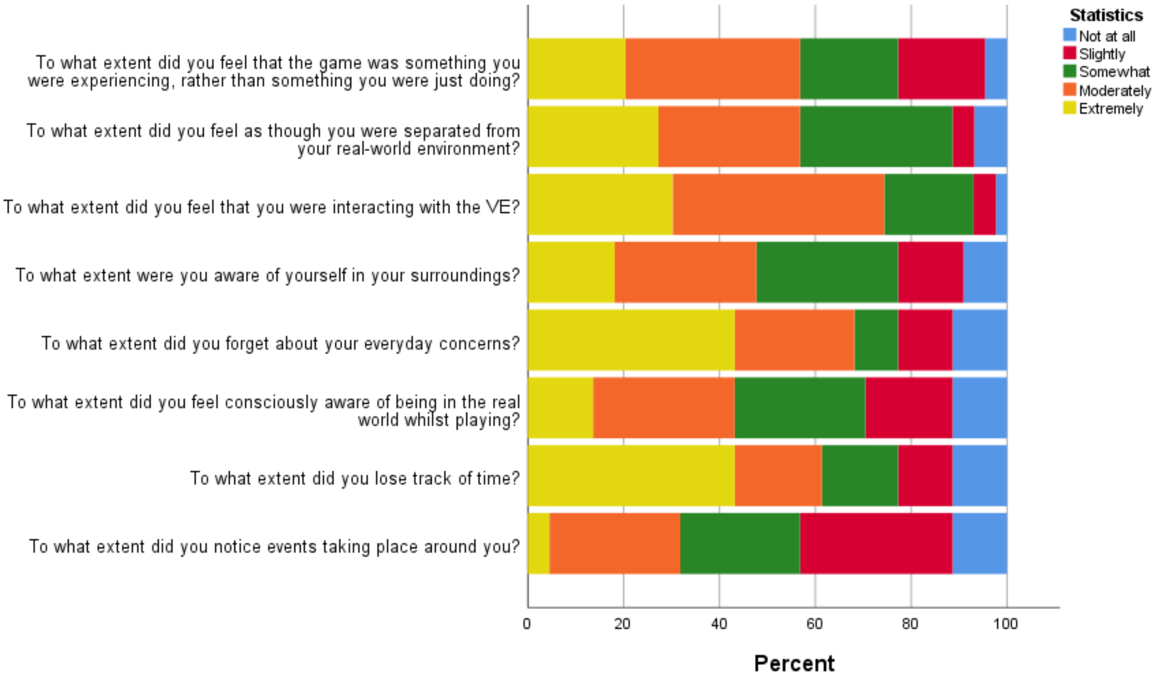


Figure 6. 28: Stacked histogram of participants feedback on immersion

The feeling of immersion has been assessed through questions measuring the loss of time and place awareness, levels of interaction with the VR environment and the sense of realism of the experience. The results indicate good levels of achieved sense of immersion using the prototype as depicted in the diagram of Figure 6. 28above. In the case of users having noticed events taking place in the real world whilst experiencing the VR prototype is correlated to the highly noisy lab environment in some cases. During the performance of the studies in the lab, there was noise from 3D printers running in the room and technicians entering which was something that could not be solved by the moderator. The XR lab was the only environment were the necessary VR equipment was available and other functions of the lab could not be terminated.

In conclusion, it can be assumed that the design approaches followed in implementing 360 video-based interactive scenes and experiences were effective in terms of engagement, usability and sense of immersion and could form as base of successful and promising solutions design.

6.7 Design Guidelines

The first phase studies allowed the derivation and specification of set of preliminary design guidelines for both the experiential as also the interactive design layers for 360 immersive video solutions. Those guidelines have been elaborated and revised by studying the results of the second phase studies. The second phase studies allowed also the derivation of new guidelines more specifically in the areas of:

- human actors’ role in terms of motivating users;
- UI design, and;
- gamified design.

The guidelines derived by the interpretation of second phase studies outcomes are described in detail in this chapter. The guidelines are presented in four parts: DG; motivation; benefit; examples, as in section 5.7.

Next, a final list of guidelines is provided by combining the outcomes of both studies and revisiting the preliminary set of DGs derived during the first phase studies. This list of design guidelines addresses the last research objective OBJ4 outlined in Section 1.1.

Through the analysis of the second phase studies results (presented in Chapter 6), twelve design guidelines for enhancing the user experience of 360-degree immersive video applications derived. Those appear categorized per 360-degree immersive video design layer (see Figure 6. 1) in the following sections, specifically:

- the experience design layer (colour coded with green below to comply with the colour coding used in Figure 6. 1), concerning the design of the *role of actors*;
- the interactive layer (colour coded with blue below to comply with colour the coding used in Figure 6. 1), concerning the design of the *UI*, and the design of *gamified* tasks.

6.7.1 Design guidelines addressing the experience design layer

Three design guidelines procure related to the role of actors in enhancing the user experience in 360-degree immersive video applications.

6.7.1.1 Actors role design

DG1: ***For information provision in 360 immersive video storytelling experiences, a combination of human actors performing as narrator along with textual communication UI panels is suggested.***

Motivation

The introduction of the story concept to users taking part in a 360-degree immersive video storytelling experiences by a human actor is natural and attracts user attention (see section 6.6.3). In storytelling experiences users have to follow and learn lots of information, even in the case that applications may not have a learning focus. To support the narration and serve the needs of any type of learner (visual and auditory learners), textual communication UI panels should be also integrated and displayed following the narrators’ speech and actions (see qualitative analysis results in section 6.6.3). The narration scenario for the actor, to help building a rapport with the users, should be carefully designed including engaging gestures (as per DG5, Section 5.7.1.3).

Benefit

Using a combination of visual and auditory elements to present the concept of the story of 360-degree immersive video storytelling experiences users can ensure the better absorbing of information by users that learn in ways.

Examples

UI textual information panels have been integrated in Scene 2 of P2-2 and subjected in comparative studies with the element of narrator integrated in Scene 1 of P2-2 (see section 6.3.2). Results (Section 6.6.3) indicated that both design techniques are accepted by the users in terms of usability and effectiveness in introducing the concept of the story and the mission. A combination of the techniques though is suggested as the most efficient design approach as it can address the needs of visual as also auditory learners.

DG2: ***Humans captured in a 360 immersive video can assist navigation and exploration of the scene content by guiding users to look towards specific areas in a scene.***

Motivation

To address the user requirement of providing direction mechanisms in 360-degree immersive VE based on video a human actor have been captured in the prototypes that have been created for the needs of the PhD research looking towards the camera aiming to create eye-contact with the viewers when entering a scene. Then the actor looked towards the direction the users should look to complete the intended task of the scene. The quantitative results analysis (in Section 6.5.3) indicate the successful effect of this technique, that besides of adding to the realism of the experience, effectively motivates the users to turn towards the direction the actor is looking to discover the POIs displayed in the 360-degree scene.

Benefit

Directing human actors during the capturing of 360-degree videos to look towards to camera and then change their view facing the POIs effectively engages the users in exploring the virtual scene in immersive video experiences. This design approach also enhances the sense of realism of the virtual experience.

Examples

A lady actor has been captured in the 360-degree videos used to create Scene 4 of P2-2 prototype instance (see section 6.3.2). When entering Scene 4 the users faced the actor and then followed her when changing view direction ending up to spotting the fountain area (POI) in the scene.

DG3: In non-fast-paced interactive experiences based on 360 immersive video, human actors should be used to motivate user to change their direction of view.

Motivation

The use of human actors can be efficiently used in motivating users of 360-degree immersive video experiences to follow their looking direction. Analysis of the data of the logging mechanism of the second study research output, showed that users turn to look towards the part of the scene to that contains a POI to be discovered much faster compared to when no navigation mechanism is included. This method of the use of human actor to assist navigation proved to be equally efficient in terms of performance compared to the use of graphic UI elements in the form of pointing vectors (see section

6.6.3, quantitative results analysis). The human actor view direction mechanism effectively addressed its purpose in all tested cases providing also a more realistic approach (see Section 6.6.3, qualitative results analysis) and adding to the user's sense of presence.

Benefit

The use of human actors to direct the user's view in a 360-degree video experience is an effective technique in terms of user performance in tasks that target the exploration of the virtual scene displayed. This technique is considered as most appropriate for non-fast-paced interactive experiences where the accomplishment of action tasks assigned to users does not depend on time.

Examples

In Scene 4 of P2-2 prototype instance (see section 6.3.2) the users were motivated to look towards the direction an actor placed in the scene was looking. This allowed users to explore the 360-degree scene and identify important areas (fountains serving as POIs) in a relaxed and realistic way.

6.7.2 Design guidelines addressing the interaction design layer

6.7.2.1 UI design

DG4: Textual communication UI panels in 360 immersive videos should include limited chunks of text.

Motivation

To address textual communication requirements in 360-degree interactive video experiences, UI panels can be designed and integrated in 3D virtual scenes where video resources are projected. To allow legibility and comfort reading of the text through the use of HMDs, the panels should display limited chunks of text (see section 6.6.1.3 qualitative results).

Benefit

Textual information displayed in immersive video experiences allows the better introduction to the context of the story and the provision of necessary feedback on interactive tasks. The chunks of text displayed in UI panels appearing in immersive video experiences should be limited in order to allow information consumption in comfort.

Examples

To communicate historical information about the area visited and the artefacts depicted during the immersive video virtual tour of P2-2, text appeared in UI panels in small chunks (see Scene 2 of P2-2 in section 6.3.2). Each panel displayed a limited chunk of text and to proceed to user should select the “next button” that dynamically updated the text.

DG5: Textual communication UI panels in 360 immersive videos should be placed in different areas around the 360-degree environment allowing the user to explore the affordances of the VE more effectively.

Motivation

Exploratory design followed in interactive experiences can make users more curious about how the story unfolds when viewing 360-degree video narratives. The user is motivated to explore the environment on their own and advance in the story by gradually discovering the rules and mechanisms used (De Valk, 2012). To assist exploratory design, UI text panels should be better placed in areas spread around the 360-degree scene that requires the change of users viewshed. The qualitative analysis of the user’s comments during the P2-2 test sessions, suggests the placement of UI text panels in areas outside the initial users viewshed to allow the exploration of each scene in a more personal way (see section 6.6.1.3).

Benefit

Users feel engaged through experiences that have positive affect on them by letting them explore the virtual environment further and offer a more personalized design (see section 4.6). As such, engagement of 360-degree immersive video viewers can be achieved through the design of interactive tasks that require the user to explore the affordances of the environment scenes on their own.

Examples

Most of the UI text communication and instruction panels have been displayed directly in front of the user's view when entering each new scene of the P2-2 prototype instance (see section 6.2).

DG6: Interactive UI buttons accompanying textual communication UI panels should be placed on the side of the panels eliminating the chance of error by selecting them accidentally and preventing users from carefully reading the displayed information.

Motivation

The use of UI panels that display text in a dynamically updated form requires the integration of accompanied interactive UI buttons that can trigger the update. Those UI action buttons should not be placed directly below the UI panels displaying textual information that need to be read carefully by the users by focusing on them Placing the action buttons right below UI panels that display textual information (as in Scene 2 of P2-2, see section 6.3.2) can lead to accidental selections when the interaction in enabled by gaze focus (though HMDs use). When experiencing Scene 2 of P2-2 the observer noted that many users were struggling to read the text by trying to avoid selecting the interaction buttons (see section 6.6.1.3 qualitative results).

Benefit

When the design of UI interaction in HMD immersive experiences is gaze-based, the placement of action buttons should be carefully designed to allow comfort of use. Integration of UI textual information panels should be also performed taking into consideration their positioning in areas not close to interaction buttons. The design should allow users to focus on reading the text displayed without worrying about performing gaze-triggered actions by mistake.

Examples

Interaction buttons have been placed just below UI text communication panels in Scene 2 of P2-2 (see section 6.3.2). That design approach should be avoided based on the qualitative results analysis of the second phase studies (see section 6.6.1.3) as some of the users commented that did not feel comfortable when trying to read the chunks of text displayed.

DG7: ***In case the goal of the designer is to provide a non-gamified, slow-paced experience, the UI should be designed following the diegetic approach.***

Motivation

The second phase studies qualitative analysis results dealing comparing the diegetic vs non-diegetic UI design approach revealed that the most appropriate design technique relies on the project’s objectives. The study results indicated that in case of targeting a non-gamified, relaxed storytelling experience, the diegetic approach has been noted as the most appropriate in satisfying user needs (see section 6.6.1.1).

Benefit

To address the user needs for a user-friendly and comfortable UI design in 360-degree immersive video experiences, the most appropriate technique should be followed according to the use-case scenario. Diegetic design approach serves the user needs for a user-friendly UI in interactive experiences that don’t follow a gamified fast-paced design.

Examples

Two different UI design approaches have been followed in the scenes of P2-1 (see section 6.3.1), the diegetic and the non-diegetic. That approach allowed the derivation and interpretation of comparative qualitative results for the two techniques depending on the use case scenario (see section 6.6.1.1) though the analysis of the user’s follow-up comments on their UI preference.

DG8: ***The use of a UI radar map element in a diegetic or non-diegetic form is considered equally important for user direction in 360 immersive videos.***

Motivation

To assist users’ orientation in 360-degree video scenes and assist them in spotting POIs captured in the scene, radar map elements were integrated in diegetic and non-diegetic form in different scenes of P2-1 (see section 6.3.1). The radar map element usefulness was evaluated through a quantitative analysis of the user's responses (see section 6.6.1.2) pointing out the importance of its use in both forms.

Benefit

When experiencing a 360-degree immersive video narrative it is important that users are provided of a means of orientation in the scene. Lack of such information mau result in user anxiety feeling they might be missing something important displayed out of their current viewshed. The use of a radar map either in diegetic, or non-diegetic from was proven to be an acceptable and efficient form of user direction mechanism.

Examples

UI radar map elements have been integrated in Scenes 1-3 (in diegetic form) and Scenes 5-7 (in non-diegetic form) of P2-2 (see section 6.3.1). The radar maps were depicting the location of POIs (ancient 3D vases) integrated in the scene in relation to the user's current view in 360-degrees. Other UI elements were also integrated in the scenes, such as a timer and a progress indicator. Radar maps were proven to be the most important UI elements of providing continuous feedback to the user and assisting them in accomplishing the assigned tasks.

DG9: Radar map UI elements in non-diegetic design should be better placed at the top-center of the user's view and have the minimum size allowing good legibility.

Motivation

A radar UI element when designed following the non-diegetic approach for 360-degree immersive video experiences viewed through HMDs, should be attached to the virtual scene camera in the form of 2D plane asset. In this way the UI element remain static and following the user viewshed. When designing the UI for VR headset immersive video experiences, information display should not distract the users from exploring the 360-degree video scene (see section 4.2.2). Results from the second phase studies concerning the use of the radar map indicated that its size should be the minimum possible, while at the same time remaining legible, and should be better displayed at the top-center position of the user’s viewshed avoiding eye-strain effects (see section 6.6.1.2).

Benefit

The design and integration of complex information UI elements, such as radar maps should target a non-distractive and non-intrusive appearance. In that way, the experience offered remains comfortable to the viewers allowing them to explore better the video scene displayed.

Examples

The radar map UI element had been integrated in Scenes 5-7 of P2-2 (see section 6.3.2) by being placed on a 2D plane attached to the virtual camera remaining always visible to the user. Its position was on the top-right of the user’s viewshed leading to eye-strain effects and visual discomfort for some of the users.

6.7.2.2 Gamified design

DG10: For the design of gamified 360 immersive video experiences the most effective and acceptable UI design approach to be followed is the non-diegetic.

Motivation

Two different UI design approaches for 360-degree immersive video experiences have been followed for the different scenes design of P2-1 and subjected to comparative user evaluation during the second phase studies, the diegetic and the non-diegetic. The results indicated that in gamified experiences such as the one introduced in P2-1 (collect objects placed in the scene at a given time), the most effective and acceptable approach for the UI elements design is the non-diegetic (see section 6.6.1.1).

Benefit

In order to provide the maximum level of usability to the users of 360-degree immersive video experiences, the UI should be designed in its most effective and user accepted form. To offer great user experiences usability should be always considered when designing UI elements.

Examples

Scenes 1-4 of P2-2 (see section 6.3.1) followed the diegetic approach for their UI in order to be compared with the user experience offered by Scenes 5-8 of P2-1 that followed the non-diegetic. User rated the non-diegetic UI approach as the one that they most preferred and the one that allowed them to accomplish the assigned action tasks in an easier way.

DG11: In gamified 360 immersive video experiences, the best UI game elements combination in terms of user performance is the use of a radar map and a progress indicator.

Motivation

In order to offer a seamless immersive experience to 360-degree interactive video, the UI should be simple, consisted by the minimum possible number of elements, displaying though the necessary information to control the experience. Different combinations of three key gamified UI design elements have been used for the scenes of P2-1 creation: a timer; a radar map; and a progress indicator. Results on user's performance, based on log mechanisms integrated to each scene to track the time needed by the user to accomplish the same task, indicate that the most effective and efficient UI elements combination is the radar map, plus the progress indicator (see section 6.6.1.2).

Benefit

The use of the most efficient combination of UI elements in the design of gamified 360-degree immersive video experiences can assure that the user will remain immersed and engaged throughout the virtual activity.

Examples

Scene 6 of P2-1 (see section 6.3.1) included a combination of a radar map and a progress indicator in their non-diegetic UI form. The pairwise comparison results for all P2-1 scenes on user's performance in terms of time required to accomplish the assigned task, revealed that users completed their task faster in Scene 6.

DG12: Introduction of challenges in the form of exploring the 360 immersive video content for spotting POIs is an important design aspect towards engaging the user.

Motivation

Two different forms of challenges were designed and integrated in different scenes of the second prototype design to support this PhD research. The first was on spotting 3D objects placed inside the video scene, while the second on spotting elements displayed by the video content used to create the virtual scene. The qualitative analysis of the corresponding results based on users' comments about their experience in the two scenes, showed that the second option was moere engaging and has greater potential towards connecting better the user to the virtual scene (see section 6.6.2).

Benefit

The design of engaging gamified experiences is an important aspect towards enhancing the level of user experience offered to immersive video viewers. Designing challenges related to the context of the video scenes is a method associated to the engagement factors of richness and control (see section 4.6). Such challenges create an arousal of thoughts to the users, while providing confidence on accomplishing assigned tasks.

Examples

In Scene 3 of P2-2 the users were requested to explore the video scene and spot an element of a specific historical period which was part of the video content. The potential areas of interest have been marked with the use of a circle (see section 6.3.2). This approach was preferred by the users compared to the integration of 3D objects in the scene that was used in P2-1, as it allowed users to pay attention to the video scene in more detail.

6.8 Summary

This chapter elaborated on the planning, performing and outcomes evaluation procedures of the second phase studies. That part of studies addressed the objectives related to the assessment of the interactive layer of the iVID methodological framework providing an evaluation on the usability and effectiveness of design techniques related to:

- UI design for 360-video based solutions for VR headsets;
- gamified experiences design;
- gamified UI elements design and integration;
- textual information provision;
- designing the roles of human actors.

Therefore, the second phase study results analysis led to the specification of design guidelines for the area of 360 video-based VR experiences that are immersive and engaging addressing the final and key objective of our research project. This section presented and provided a detailed analysis for the derivation of 12 design guidelines that originated based on the results of the evaluation of the second phase prototypes created to support this PhD research with users. Those design guidelines enhance the preliminary list provided by the first phase studies.

Chapter 7

7 Conclusion

This chapter provides an overview of the current thesis, a clear definition of contributions to knowledge in the field of 360-degree immersive video design to support good user experience and a discussion of the benefits to the recipients impacted by the research output. The chapter revisits the research objectives and discusses how those have been addressed. The main conclusions are discussed followed by the plan for future studies. The chapter concludes with a summary of the research project described in this thesis.

7.1 Contributions

This research project aimed to address a set of objectives defined in the area of 360-degree immersive video, as outlined in Section 1.1.

> **OBJ1:** the first objective was to identify the challenges imposed when using 360-degree videos to create interactive and immersive experiences for VR headsets;
> **OBJ2:** the second objective was the specification of a rigorous methodology for the analysis of the design aspects in the area of 360-degree immersive video solutions and corresponding techniques that could be followed;
> **OBJ3:** the third objective was the analysis of the procedure for developing working 360-degree immersive video prototypes following the proposed rigorous methodological steps t and the incorporation of the identified design techniques;
> **OBJ4:** the final objective was the derivation of a set of design guidelines for the design and development of 360-degree immersive video solutions aiming to provide interactive and engaging experiences.

The contributions achieved to address the targeted objectives of this PhD research are detailed in the following subsections.

7.1.1 Specification of challenges in designing engaging 360-degree immersive video experiences

At the beginning of this project, the needs, and problems in designing engaging interactive experiences for VR headsets with the use of 360-degree video have been analysed followed by a specification of the technological implications and design issues (see sections 3.1 & 3.2). These issues have been defined after an analysis of SoA, thorough literature review of related research work on 360-degree immersive video and preliminary experimentation and observations with 360-degree video production and VR prototype solutions development. The design requirements for this new medium (see section 4.1) have been also based on discussions with UK based media production companies based. This survey led to the specification of a list of six challenges both at technical and design level (see Section 4.2). Those challenges are summarised in the Table 7. 1 below.

Technical challenges	
Ch1:	Smooth transition between video resources
Ch2:	Natural, close to real environment
Ch3:	Reality-based navigation
Design challenges	
Ch4:	Non-intrusive, non-distractive user interface design
Ch5:	Navigation and orientation mechanisms
Ch6:	Gamified design

Table 7. 1: Challenges in designing 360-degree immersive video interactive solutions

This initial list of challenges that has been identified provides an initial contribution within the area of 360-degree immersive video that defines the key aspects that researchers need to focus when studying the design of engaging experiences (Argyriou, et al., 2016).

7.1.2 Design methodology in 360-degree immersive video solutions

The second objective focused on defining a rigorous methodology in designing good 360-degree immersive video experiences. The research addressed this objective by proposing a dedicated methodological framework that analyses the necessary design aspects and key factors contributing in creating engaging and immersive experiences using 360-degree video. This methodological framework serves its purpose on understanding the key design processes for 360-degree immersive video production and proposes a categorization of design aspects and techniques to lead the definition of applicable methods. The methodological framework breaks down the necessary design tasks of the experiential and design layer and provides a taxonomy of factors related to immersion, engagement and usability that need to be considered for each task. The analysis concludes with a set of proposed methods that correspond to each factor (see Sections 4.9.2 and 4.9.4). The iVID framework is the final output of the methodological procedure proposed that divides the process of 360-degree immersive video creation in six stages (see Section 4.9):

Stage 1: Requirements analysis
Stage 2: Experience design
Stage 3: Story design
Stage 4: Interaction design

Stage 5: Scenes design

Stage 6: Prototype development

7.1.3 360-degree immersive video prototypes

In order to be able to proceed with the creation of prototype solutions of 360-degree immersive video, there is a need for defining an architectural concept that depicts the development processes in a clear and structured way. This concept should incorporate the iVID methodology providing an example of its application and use in the development of working applications.

Such an analysis is provided through an architectural prototyping concept presented in section 4.9.6. The architecture defined depicts the two key processes in developing 360-degree immersive video prototype applications: the video content production and the prototype development and integration. The procedural flow and concrete design and production steps have been specified for each of the two processes. The processes relation to the iVID methodological framework is presented and explained. Prototype design techniques are also analysed as possible methods for addressing the identified challenges at the beginning of the project (see section 4.2).

To validate the architectural concept introduced and to evaluate the methodology developed and the applicability of the selected design techniques, two different prototype applications have been developed. Those applications served as experimental tools for this project and were used in two phases of user experience research studies (see Chapters 5 and 6).

The two prototypes were formed to serve the purpose of virtual informative tours in a historical city. The detailed methodological procedure for developing the prototypes using iVID is presented are in sections 5.2 and 6.2 respectively. The design analysis of the two prototypes also provides a definition of how the proposed design methods and techniques can be incorporated.

By providing a specification of how the iVID framework could be followed in the design process of developing 360-degree immersive video prototypes and a detailed description of the design process for two applications, the third objective of the project is also addressed.

7.1.4 Design guidelines for 360-degree immersive video

The final and most important objective of this research project was the extraction of design guidelines applicable for 360-degree immersive video solutions. To serve this target, two phases of user studies have been designed using the research prototypes developed (see Chapters 5 and 6). The first phase studies targeted the evaluation of a set of design techniques driven from the iVID framework and incorporated in the design of the first prototype. The qualitative and quantitative analysis of the results of the first phase studies and their interpretation led to the definition of eleven (11) design guidelines (see Section 5.7). The second phase studies aimed to re-evaluate some of these guidelines and extend the list by extracting new ones through the incorporation of different techniques in the prototype used. Twelve (12) additional guidelines have been also extracted from the analysis of the second phase studies results (see Section 6.7).

A complete list of twenty-three (23) design guidelines has been provided as an output of both studies. This list of design guidelines is categorized per design layer and aspect targeted:

- experience design (9): narrative design (2), virtual scenes design (2), actor's role design (5);
- interactive design (14): navigation design (2), UI design (6), gamified design (6).

The complete list of design guidelines that derive from both phases of this PhD research related to both the experience and interactive layers of 360-degree immersive video experiences is provided in Table 7. 2 below. Twenty-three DGs comprise this final list, those are categorised per design layer and design aspect targeted.

Design guidelines (DG) addressing the experience design layer	
Narrative design	
DG1:	The design of the story of the application should follow a real-life application scenario.
DG2:	The design of the narrative should follow a branching storytelling approach to further engage the user to the story.
Virtual scenes design	
DG3:	Each virtual scene should depict a set of POIs relative to the story.

DG4:	The UI graphic elements with textual information should be placed in positions close to the POIs but without hiding them.
Actor’s role design	
DG5:	Human actors used as narrators in immersive video scenes should be provided with a scenario describing storytelling movements to perform as they speak.
DG6:	Human actors used as navigation motivators influencing the user’s view rotation should be provided with a scenario describing the exact actions to perform to create human eye-contact.
DG7:	For information provision in 360 immersive video storytelling experiences, a combination of human actors performing as narrator along with textual communication UI panels is suggested.
DG8:	Humans captured in a 360 immersive video can assist navigation and exploration of the scene content by guiding users to look towards specific areas in a scene.
DG9:	In non-fast-paced interactive experiences based on 360 immersive video, human actors should be used to motivate user to change their direction of view.
Design guidelines addressing the interactive design layer	
Navigation design	
DG10:	Moderate motion effects should be integrated through short and steady walking simulation videos.
DG11:	Location reference of POIs can be effectively given though the integration of graphic pointing vectors.
UI design	
DG12:	Textual communication UI panels in 360 immersive videos should include limited chunks of text.
DG13:	Textual communication UI panels in 360 immersive videos should be placed in different areas around the 360-degree environment allowing the user to explore the affordances of the VE more effectively.
DG14:	Interactive UI buttons accompanying textual communication UI panels should be placed on the side of the panels eliminating the chance of error by selecting them accidentally and preventing users from carefully reading the displayed information.
DG15:	In case the goal of the designer is to provide a non-gamified, slow-paced experience, the UI should be designed following the diegetic approach.
DG16:	The use of a UI radar map element in a diegetic or non-diegetic form is considered equally important for user direction in 360 immersive videos.
DG17:	Radar map UI elements in non-diegetic design should be better placed at the top-center of the user’s view and have the minimum size allowing good legibility.
Gamified design	
DG18:	Challenges can engage the users if integrated in each scene in the form of multiple answer questions on text panels.
DG19:	Users should be notified about their achievements on addressing the challenges through visual information.
DG20:	The design of challenges should follow a level-up approach informing the users through scoring visual mechanisms.
DG21:	For the design of gamified 360 immersive video experiences the most effective and acceptable UI design approach to be followed is the non-diegetic.
DG22:	In gamified 360 immersive video experiences, the best UI game elements combination in terms of user performance is the use of a radar map and a progress indicator.
DG23:	Introduction of challenges in the form of exploring the 360 immersive video content for spotting POIs is an important design aspect towards engaging the user.

Table 7. 2: Design Guidelines for 360-degree immersive video experiences

7.2 Limitations

There were several limitations in addressing this PhD research objectives, which are summarised as follows:

- limited research work in this new area of immersive solutions design;

  At the beginning of this research project in 2016, not many research studies and results were available for literature review due to the recent release of VR headset devices that could provide and immersive experience of 360-degree video resources. Moreover, 360-degree immersive video was first introduced in a non-interactive form, with interactivity being possible only though post-production with the use of game engines. Issues though still existed with video display when editing and building 3D applications making the 3D scenes creation difficult.

- limited amount of media producers dealing with immersive video production, that could define production design guidelines;

  The issue of nausea effects as a result of experiencing 360-degree immersive videos through VR headsets was an important reason for preventing production companies from investing in this new form of media. Capturing with locomotion was not recommended also, as it could easily lead to motion sickness. The production companies need to invest in technical personnel as the design of interactivity is only feasible though game engines that require knowledge in games programming.

- lack of an exclusive design process and methods for designing 360-degree immersive video;

  The process of creating 360-degree immersive video resources with interactivity is still vague with limited guidelines available. Several methods and design techniques driven from the area of VR, or traditional video production were not applicable in this case.

- difficulties in 360-degree video production;

  360-degree video production using a low-cost device required time and experimentation with the medium. Issues with motion sickness were noted during initial stages of the study, while conducting preliminary research and experimentation of viewing videos captured with locomotion. Frequent, short, pilot studies engaging a small sample of users, including the researcher, had to serve as the initial experimental subject to validate that the developed experimental prototypes were safe for the studies. Video production process needed to be planned in good weather conditions, in daylight and in not crowded areas and times to be able to control movement and subjects captured. Video content for this study has been captured using a low-budget 360-degree video camera, but to produce high-quality video content with stabilization, equipment of high cost is required.

- need for digital assets in 3D and 2D form to design interactive tasks;

  To create the UI required to support interactivity and experiment by enhancing the video scenes with 3D objects, several digital assets were required. The creation of such artefacts required archaeological documentation that was beyond the requirements of this PhD research, therefore those were acquired from free online historically reliable digital asset libraries. The experimentation with 3D photogrammetric reconstructed objects was not possible, as there were no such available libraries of artefacts of the area and period chosen as case study for the prototypes’ development (for example online digital museum collections).

- development effort to produce the prototypes;

  The 360-degree video production process, which is the first phase for creating 360-degree immersive video experiences (see section 4.9.6), requires investment of considerable time and effort. The post-production phase that is required for the creation of interactive immersive solutions for VR headsets using 360-degree video resources can be achieved using a game engine. This process requires effort also in programming and 3D games design.

- time constraints in performing user studies;

  The research project lifecycle was restricted in time making it difficult to plan and perform several user studies. The user studies require good time planning, reserving special equipment and rooms and recruiting real users.

- people denial in using VR headsets.

  Many people feel distressed with the idea of experiencing nausea or motion sickness effects when using VR headsets, or simply do not want to use such devices. This makes it hard in recruiting participants for conducting user testing studies.

7.3 Beneficiaries, communities impacted by the research output

The contribution of a systematic design methodology for 360-degree immersive video solutions could be beneficial for several communities such as:

- professionals dealing with immersive video production;
- developers UX/UI designers of immersive video interactive solutions;
- HCI and UX researchers;
- educational solutions professionals and researchers.

Professionals dealing with immersive video production (Immersive video producers, production designers and art directors) could benefit from the introduction of problems of this new form of media that need to be resolved before proceeding with investing in this technology (see Section 4.2) pointing our also the risks and implications of a non-systematic design approach (see section 3.1, and 3.2). They are also provided with a methodological specification of design aspects and techniques that should be considered at the experience design layer (see Section 4.7 and 4.9.2). This categorization assists the specification of methods and processes that should be followed before proceeding to the video production phase justifying also the necessity of a rigorous specification of what and how should be captured. Further analysis of the video production design phase for creating immersive solutions (see Section 4.9.6) is also provided and mapped to the other development phases to point out its importance and correlation. A set of validated though user studies design guidelines are also introduced referring to the importance of using actors, carefully designing interactive forms of narratives and systematic scenes design. These guidelines should be considered at the video production process specification stage and also during capturing of 360-degree video if aiming to provide comfortable, user-friendly and engaging immersive experiences (see sections 5.7 & 6.7).

Developers and UX/UI designers of immersive video interactive solutions are expected to benefit from the introduction of the iVID methodological framework as it provides in a systematic way for defining the processes and design methods that need to be followed in 360-degree immersive and interactive solutions production (See Section 4.9). In addition, the presentation of an architectural concept as the last stage of iVID (see section 4.9.6) that defines the development procedural steps is also considered as an important tool that analyses the whole process in a more systematic way. Moreover, the list of 23 design guidelines introduced (see sections 5.7, 6.7 & 7.1.4) addresses the challenges imposed by this technology and also provides key directions in creating effective and efficient new forms of engaging experiences. The methodological design analysis, based on the use of the iVID framework (see sections 5.2 & 6.2), of two prototype applications provide further evidence on its applicability and could motivate this community in creating similar solutions for CH or other fields.

HCI and UX researchers can also benefit from this research work in defining new ways of addressing issues and challenges introduced by the design of engaging 360-degree immersive video experiences. In addition, this PhD research contributions of the iVID methodology and the list of design guidelines to be followed in approaching the design of 360-degree immersive video experiences provide a starting point in addressing the problem in this area pointing out the need also for further studies. The methodology followed for defining iVID provide key insights on how such complex HCI and UX research problems could be systematically addressed. The actual raw data produced from the two different studies, that have been conducted as part of this PhD work, is also available to the research community for further analysis and interpretation.

Educational solutions professionals and researchers are introduced to a new form of immersive virtual tour experiences that could serve as an interactive educational or serious games application in various domains such as History or Geo-sciences. A set of preliminary gamified design guidelines has been defined (see sections 5.7 & 6.7) to assist them in developing similar solutions to the ones presented and also motivate them for future experimentation with 360-degree immersive solutions design. The two prototypes developed and introduced (see Chapters 5 & 6), that have incorporated gamified techniques and methods using iVID, could also inspire and motivate them for working on the development of complete serious games solutions based on 360-degree video. Finally, the iVID methodological framework could also be studied under the scope to serve as a base for defining a dedicated Serious games/Immersive Education framework for 360-degree immersive video.

7.4 Future directions

The intended future work directions are divided in four different areas:

- methodology;
- immersive cultural heritage;
- pedagogy;
- design guidelines.

7.4.1 Methodology

The methodology provided in the form of the iVID framework could be extended in the future by providing a more detailed analysis of the tasks and corresponding techniques. This research project has focused on the key design aspects in the area of 360-degree immersive video. Not every aspect of design at the experience design or the interaction design layers has been covered. The methodology could be further enhanced through dedicated extensive surveys with immersive media producers aiming to captivate their current needs and get feedback from recent developments in the area. This process is expected to lead to more detailed definition of the aspects that need to be considered and corresponding methods for the experience design. The interaction layer taxonomy could be also elaborated by recording new requirements of designers and developers dealing with MR (Mixed Reality) technologies that are relevant to immersive video solutions design.

Further design techniques could be exploited, and a more thorough analysis of the design tasks could be formed aiming to provide a more concrete and detailed taxonomy.

7.4.2 Immersive Cultural Heritage

The two prototype solutions that have been developed served as case studies for Immersive Cultural Heritage. The results of the two studies indicate the potentials of creating effective interactive virtual tours based on immersive video to promote areas of historical interest such as the Rethymno Historical centre. Following the design concept introduced in this research project and the list of design guidelines proposed, other prototypes could be developed to serve as new immersive experiences for promoting Cultural Heritage. These tours could either focus in archeological landscapes, other historical cities, or even indoor CH areas such as museums and art exhibitions.

7.4.3 Pedagogy

The gamified design concept and techniques incorporated in the two different prototypes developed to serve the research studies, were based on learning activities. This project though focus was not to assess the pedagogical value of the developed solutions through the evaluation of learning outcomes after the experiences provided. Future studies are planned to focus on the analysis and incorporation of the educational design aspect, extending also the iVID methodology.

The prototypes challenges and information provision design tasks could be designed to follow a more concrete educational scenario in future versions. This is feasible due to the easy adaptation of the solutions developed to serve such concepts. Comparative studies could be also designed under the scope the provide benchmarking results of this new kind of immersive CH experiences.

7.4.4 Design guidelines

The design guidelines have been formed based on the analysis of the data collected during the two user studies of this project. This data could be replicated and used for further statistical analysis that could expand the DGs list. Moreover, future studies could focus on the development of new versions of the prototypes focusing to assess more thoroughly one design aspect at time. This approach, that was not possible during the time frame of this project, is expected to lead to the extraction of more valid results on the user experience offered by each mechanism. As the design guidelines are generalized at the moment for 360-degree immersive solutions, further studies could be designed aiming to provide specific guidelines per use case scenario and targeting a certain industry. Specific fields that could be exploited are immersive journalism, immersive art, immersive education, and immersive marketing solutions design based on 360-degree video.

The use of more complex tools for data collection such as dedicated software that can produce gaze-focus heatmaps or the use EEG equipment for behavioral and cognitive analysis is expected to provide further insights on the design approaches followed.

7.5 Summary

This research project provided an understanding of the design considerations in the area of 360-degree immersive video. One of its main contributions was the introduction of a systematic methodology for designing 360-degree immersive video experiences summarized in the form of the iVID framework.

The rigorous analysis of the design aspects and corresponding methods and techniques that should be considered when designing 360-degree immersive video solutions with interactivity is important for future developments in the broad area of Virtual Reality.

The final objective to extract design guidelines for this technology has driven also the development of sample prototype solutions producing key insights on the potentials of the use of 360-degree video. The specification of the way user studies should be designed in this field and the tools and methods that need to be applied for quantitative and qualitative data collection and analysis is important for the academic research community.

The list of guidelines introduced, and the methodological approach defined for guiding the design of 360-degree immersive video applications, the iVID framework, provide a systematic way for creating user-friendly, engaging, and immersive experiences that has been validated through extensive user studies. Without following a methodological analysis of the design procedure based on UX research studies evidence before proceeding to the development stage the is high risk of developing solutions that do not address the specific needs and characteristics of the users targeted. Further than that, for the case of 360-degree immersive video experienced though HMD’s there is also the risk of creating more passive than interactive experiences (being unable to address the complexity of design issues and implications in this area – see section 3.2) that cannot achieve the desired levels of engagement of the targeted audience and even lead to discomfort due to cybersickness effects (see section 3.1).

Future directions have been also identified: to enhance the methodology introduced though further studies and stakeholder surveys; to focus on new forms of immersive Cultural Heritage solutions design; to study the educational potentials of this technology and provide contributions to the immersive learning field; and to extend the design guidelines by focusing on more targeted fields such as the serious games design.

To conclude, this research work has provided important contributions in the field of 360-degree immersive video and the area of immersive solutions design in general. Directions on the application of the research outputs have been defined aiming to inspire future research works and developments.

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Appendix I – First phase studies

I.1 Questionnaire

PART A - Demographic & General Questions

Age:

○ 18-25
○ 26-30
○ 31-40
○ 41-50
○ 50 +

Gender:

○ Female ○ Male

Please state your Academic level background and field of studies:

How often do you tend to play digital games?

○ Everyday
○ Several times in a week
○ Once in a month
○ Every two-three months
○ I don’t usually play games

Have you ever had a VR immersive experience in the past?

○ Once
○ Up to five times

○ Up to ten times

○ Never

What’s your previous experience with a VR headset?

○ Never used it

○ I’ve used it once

○ I’ve used it a couple of times

○ I use it frequently

○ I have a wide experience of VR headsets

Please mark which ones you have used in the past.

○ Oculus VR

○ HTC Vive

○ Samsung Gear VR

○ Google Cardboard

○ Other

PART B - Ottoman Fountains Tour Evaluation Questions

		strongly agree	agree	neither agree nor disagree	disagree	strongly disagree
1	**The virtual tour was engaging**	1	2	3	4	5
2	**The virtual tour was interesting**	1	2	3	4	5
3	**The virtual tour felt real**	1	2	3	4	5
4	**I felt comfortable during this experience**	1	2	3	4	5
5	**I really enjoyed the virtual tour**	1	2	3	4	5
6	**The interaction with the UI elements in the scene was smooth and natural**	1	2	3	4	5
7	**It was easy to move around in the city and reach my target**	1	2	3	4	5
8	**It felt natural and comfortable to look around in the scene**	1	2	3	4	5
9	**It was easy to understand how to accomplish the game tasks/challenges**	1	2	3	4	5
10	**The user interface elements were distractive**	1	2	3	4	5
11	**I felt tired during my experience in this virtual environment**	1	2	3	4	5

12	**I felt dizzy during my experience in this virtual environment**	1	2	3	4	5
13	**I could not easily accomplish what I was asked to do**	1	2	3	4	5
14	**I had clear instructions to complete the tasks**	1	2	3	4	5
15	**The walking simulation was smooth and comfortable**	1	2	3	4	5
16	**The teleportation to another scene was smooth and comfortable**	1	2	3	4	5
17	**I preferred the walking simulation than the teleportation**	1	2	3	4	5
18	**I would like to have a similar experience in the future**	1	2	3	4	5
19	**I felt that I had control of my experience**	1	2	3	4	5
20	**I felt excited with that kind of experience**	1	2	3	4	5
21	**I was focused throughout my experience**	1	2	3	4	5
22	**I felt like I lost track of time**	1	2	3	4	5
23	**I felt comfortable using the Virtual Reality Headset**	1	2	3	4	5

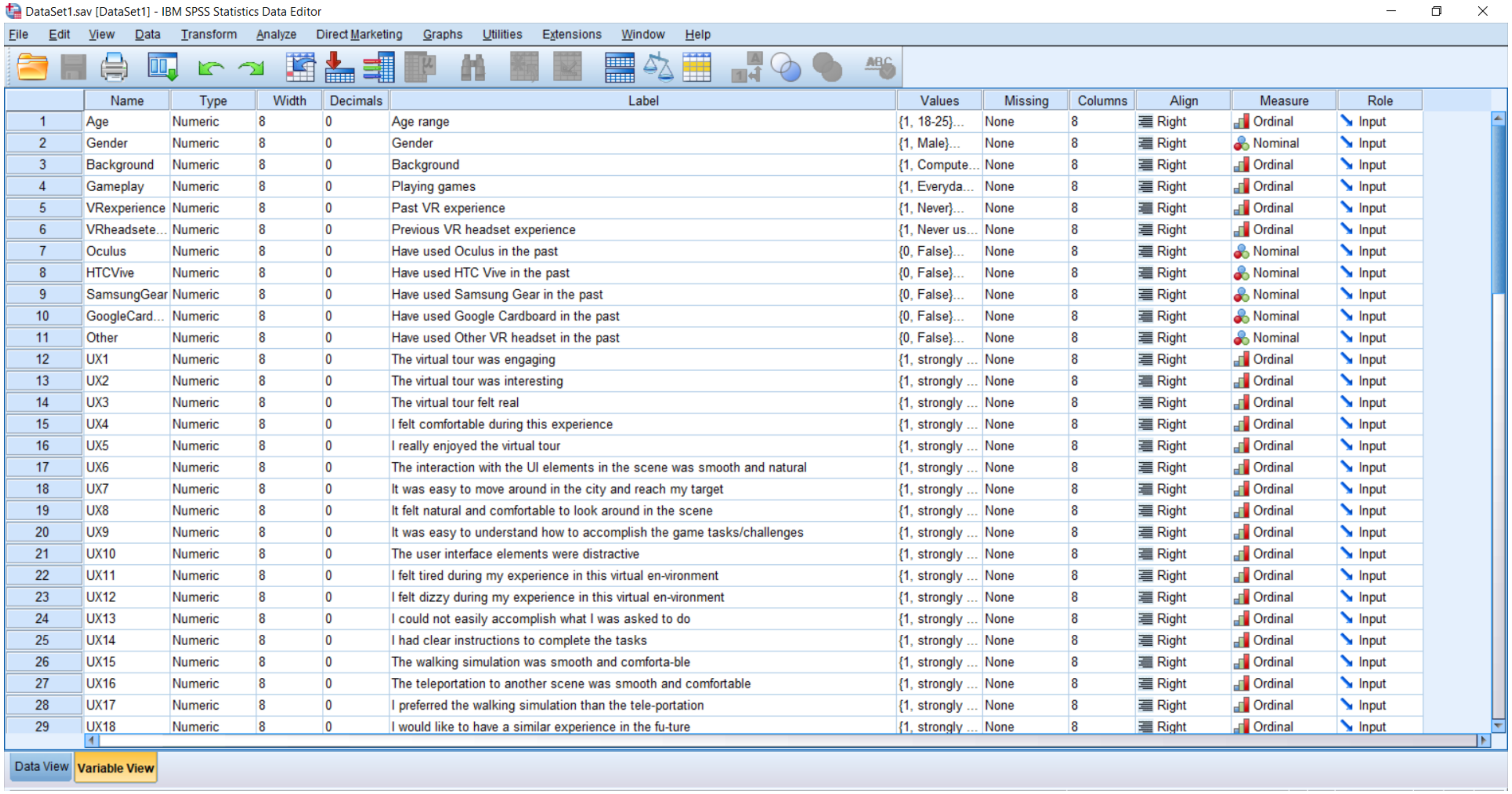
24	**I felt like I actually visited the place**	1	2	3	4	5
25	**I was motivated to look in the direction where the human actor was looking**	1	2	3	4	5
26	**I was motivated to look in the direction that the vectors were pointing**	1	2	3	4	5
27	**I prefer to change my view motivated by the human actor to vectors**	1	2	3	4	5
28	**I prefer to have no assistance of where to look and explore the environment at my own pace**	1	2	3	4	5
29	**I liked the freedom I had to choose my own path to visit a fountain**	1	2	3	4	5
30	**I prefer the natural sound than the music in the background**	1	2	3	4	5
31	**I would like to spend more time in the virtual tour**	1	2	3	4	5
32	**I would like to spend more time when visiting an area**	1	2	3	4	5
33	**I did not feel distracted by any physical environment sounds or people during the virtual tour experience**	1	2	3	4	5
34	**I felt that I was totally involved in the virtual environment experience**	1	2	3	4	5
35	**I experienced significant delay between my actions and expected outcomes**	1	2	3	4	5

36	**I quickly adjusted to the virtual environment experience**	1	2	3	4	5

Interview Questions:

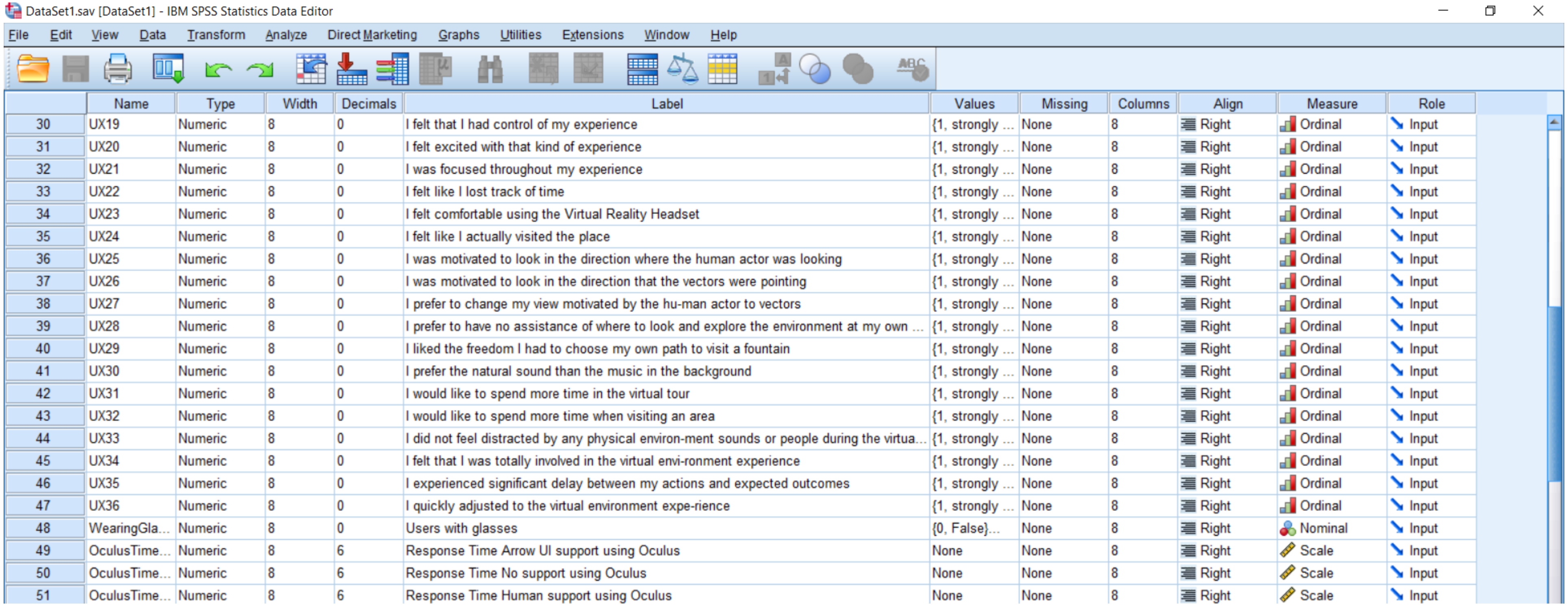
☐ Which parts of the experience did you like most and why?
☐ Which parts of the experience and why did you like least and why?
☐ To what extent were there times during the experience when the virtual environment was the reality for you?
☐ Which VR device did you prefer for such an experience and why?

I.2 Variables



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Age	Numeric	8	0	Age range	{1, 18-25}...	None	8	Right	Ordinal	Input
2	Gender	Numeric	8	0	Gender	{1, Male}...	None	8	Right	Nominal	Input
3	Background	Numeric	8	0	Background	{1, Compute...	None	8	Right	Ordinal	Input
4	Gameplay	Numeric	8	0	Playing games	{1, Everyda...	None	8	Right	Ordinal	Input
5	VRexperience	Numeric	8	0	Past VR experience	{1, Never}...	None	8	Right	Ordinal	Input
6	VRheadsete...	Numeric	8	0	Previous VR headset experience	{1, Never us...	None	8	Right	Ordinal	Input
7	Oculus	Numeric	8	0	Have used Oculus in the past	{0, False}...	None	8	Right	Nominal	Input
8	HTCVive	Numeric	8	0	Have used HTC Vive in the past	{0, False}...	None	8	Right	Nominal	Input
9	SamsungGear	Numeric	8	0	Have used Samsung Gear in the past	{0, False}...	None	8	Right	Nominal	Input
10	GoogleCard...	Numeric	8	0	Have used Google Cardboard in the past	{0, False}...	None	8	Right	Nominal	Input
11	Other	Numeric	8	0	Have used Other VR headset in the past	{0, False}...	None	8	Right	Nominal	Input
12	UX1	Numeric	8	0	The virtual tour was engaging	{1, strongly ...	None	8	Right	Ordinal	Input
13	UX2	Numeric	8	0	The virtual tour was interesting	{1, strongly ...	None	8	Right	Ordinal	Input
14	UX3	Numeric	8	0	The virtual tour felt real	{1, strongly ...	None	8	Right	Ordinal	Input
15	UX4	Numeric	8	0	I felt comfortable during this experience	{1, strongly ...	None	8	Right	Ordinal	Input
16	UX5	Numeric	8	0	I really enjoyed the virtual tour	{1, strongly ...	None	8	Right	Ordinal	Input
17	UX6	Numeric	8	0	The interaction with the UI elements in the scene was smooth and natural	{1, strongly ...	None	8	Right	Ordinal	Input
18	UX7	Numeric	8	0	It was easy to move around in the city and reach my target	{1, strongly ...	None	8	Right	Ordinal	Input
19	UX8	Numeric	8	0	It felt natural and comfortable to look around in the scene	{1, strongly ...	None	8	Right	Ordinal	Input
20	UX9	Numeric	8	0	It was easy to understand how to accomplish the game tasks/challenges	{1, strongly ...	None	8	Right	Ordinal	Input
21	UX10	Numeric	8	0	The user interface elements were distractive	{1, strongly ...	None	8	Right	Ordinal	Input
22	UX11	Numeric	8	0	I felt tired during my experience in this virtual en-vironment	{1, strongly ...	None	8	Right	Ordinal	Input
23	UX12	Numeric	8	0	I felt dizzy during my experience in this virtual en-vironment	{1, strongly ...	None	8	Right	Ordinal	Input
24	UX13	Numeric	8	0	I could not easily accomplish what I was asked to do	{1, strongly ...	None	8	Right	Ordinal	Input
25	UX14	Numeric	8	0	I had clear instructions to complete the tasks	{1, strongly ...	None	8	Right	Ordinal	Input
26	UX15	Numeric	8	0	The walking simulation was smooth and comforta-ble	{1, strongly ...	None	8	Right	Ordinal	Input
27	UX16	Numeric	8	0	The teleportation to another scene was smooth and comfortable	{1, strongly ...	None	8	Right	Ordinal	Input
28	UX17	Numeric	8	0	I preferred the walking simulation than the tele-portation	{1, strongly ...	None	8	Right	Ordinal	Input
29	UX18	Numeric	8	0	I would like to have a similar experience in the fu-ture	{1, strongly ...	None	8	Right	Ordinal	Input

Appendix Figure I. 1: First phase studies - Part A of the questionnaire variables



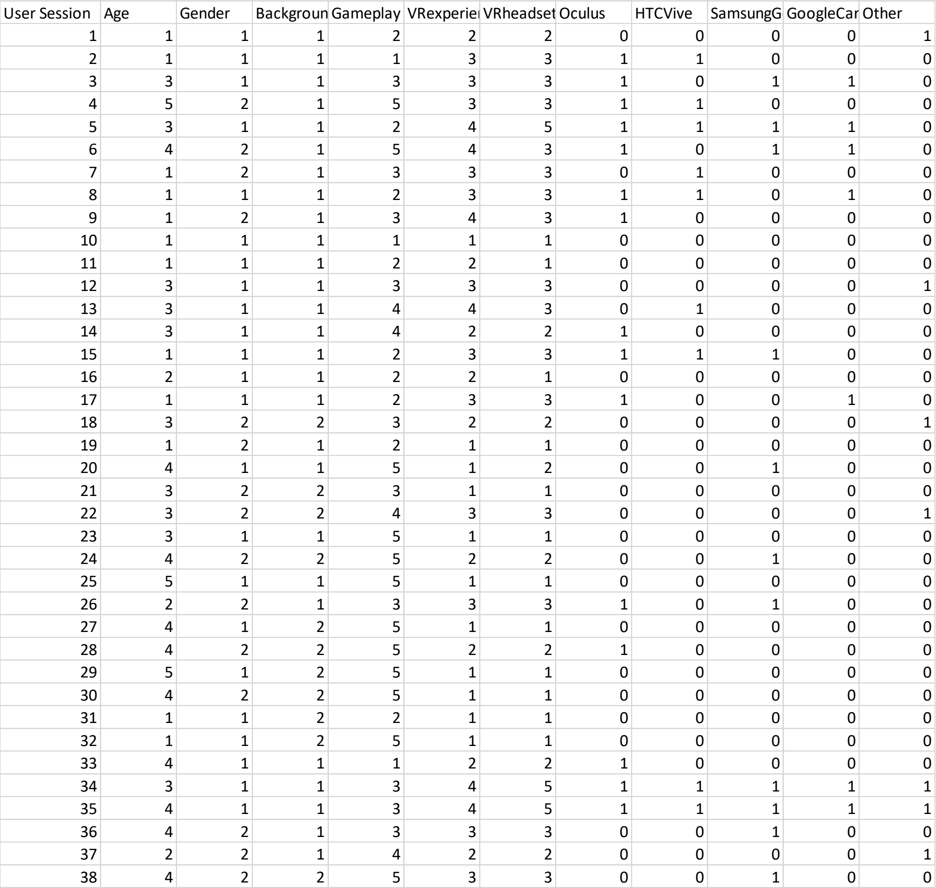
	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
30	UX19	Numeric	8	0	I felt that I had control of my experience	{1, strongly ...	None	8	Right	Ordinal	Input
31	UX20	Numeric	8	0	I felt excited with that kind of experience	{1, strongly ...	None	8	Right	Ordinal	Input
32	UX21	Numeric	8	0	I was focused throughout my experience	{1, strongly ...	None	8	Right	Ordinal	Input
33	UX22	Numeric	8	0	I felt like I lost track of time	{1, strongly ...	None	8	Right	Ordinal	Input
34	UX23	Numeric	8	0	I felt comfortable using the Virtual Reality Headset	{1, strongly ...	None	8	Right	Ordinal	Input
35	UX24	Numeric	8	0	I felt like I actually visited the place	{1, strongly ...	None	8	Right	Ordinal	Input
36	UX25	Numeric	8	0	I was motivated to look in the direction where the human actor was looking	{1, strongly ...	None	8	Right	Ordinal	Input
37	UX26	Numeric	8	0	I was motivated to look in the direction that the vectors were pointing	{1, strongly ...	None	8	Right	Ordinal	Input
38	UX27	Numeric	8	0	I prefer to change my view motivated by the hu-man actor to vectors	{1, strongly ...	None	8	Right	Ordinal	Input
39	UX28	Numeric	8	0	I prefer to have no assistance of where to look and explore the environment at my own ...	{1, strongly ...	None	8	Right	Ordinal	Input
40	UX29	Numeric	8	0	I liked the freedom I had to choose my own path to visit a fountain	{1, strongly ...	None	8	Right	Ordinal	Input
41	UX30	Numeric	8	0	I prefer the natural sound than the music in the background	{1, strongly ...	None	8	Right	Ordinal	Input
42	UX31	Numeric	8	0	I would like to spend more time in the virtual tour	{1, strongly ...	None	8	Right	Ordinal	Input
43	UX32	Numeric	8	0	I would like to spend more time when visiting an area	{1, strongly ...	None	8	Right	Ordinal	Input
44	UX33	Numeric	8	0	I did not feel distracted by any physical environ-ment sounds or people during the virtua...	{1, strongly ...	None	8	Right	Ordinal	Input
45	UX34	Numeric	8	0	I felt that I was totally involved in the virtual envi-ronment experience	{1, strongly ...	None	8	Right	Ordinal	Input
46	UX35	Numeric	8	0	I experienced significant delay between my actions and expected outcomes	{1, strongly ...	None	8	Right	Ordinal	Input
47	UX36	Numeric	8	0	I quickly adjusted to the virtual environment expe-rience	{1, strongly ...	None	8	Right	Ordinal	Input
48	WearingGla...	Numeric	8	0	Users with glasses	{0, False}...	None	8	Right	Nominal	Input
49	OculusTime...	Numeric	8	6	Response Time Arrow UI support using Oculus	None	None	8	Right	Scale	Input
50	OculusTime...	Numeric	8	6	Response Time No support using Oculus	None	None	8	Right	Scale	Input
51	OculusTime...	Numeric	8	6	Response Time Human support using Oculus	None	None	8	Right	Scale	Input

Appendix Figure I. 2: First phase studies - Part B of the questionnaire variables

I.3 Data

The data from the First phase studies are available for download in Excel form at:

https://drive.google.com/open?id=1s4Pk0z7Sd2e4VHXaafJZB-IXDS3fGtjy



User Session	Age	Gender	Backgroun	Gameplay	VRexperie	VRheadset	Oculus	HTCVive	SamsungG	GoogleCar	Other
1	1	1	1	2	2	2	0	0	0	0	1
2	1	1	1	1	3	3	1	1	0	0	0
3	3	1	1	3	3	3	1	0	1	1	0
4	5	2	1	5	3	3	1	1	0	0	0
5	3	1	1	2	4	5	1	1	1	1	0
6	4	2	1	5	4	3	1	0	1	1	0
7	1	2	1	3	3	3	0	1	0	0	0
8	1	1	1	2	3	3	1	1	0	1	0
9	1	2	1	3	4	3	1	0	0	0	0
10	1	1	1	1	1	1	0	0	0	0	0
11	1	1	1	2	2	1	0	0	0	0	0
12	3	1	1	3	3	3	0	0	0	0	1
13	3	1	1	4	4	3	0	1	0	0	0
14	3	1	1	4	2	2	1	0	0	0	0
15	1	1	1	2	3	3	1	1	1	0	0
16	2	1	1	2	2	1	0	0	0	0	0
17	1	1	1	2	3	3	1	0	0	1	0
18	3	2	2	3	2	2	0	0	0	0	1
19	1	2	1	2	1	1	0	0	0	0	0
20	4	1	1	5	1	2	0	0	1	0	0
21	3	2	2	3	1	1	0	0	0	0	0
22	3	2	2	4	3	3	0	0	0	0	1
23	3	1	1	5	1	1	0	0	0	0	0
24	4	2	2	5	2	2	0	0	1	0	0
25	5	1	1	5	1	1	0	0	0	0	0
26	2	2	1	3	3	3	1	0	1	0	0
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31	1	1	2	2	1	1	0	0	0	0	0
32	1	1	2	5	1	1	0	0	0	0	0
33	4	1	1	1	2	2	1	0	0	0	0
34	3	1	1	3	4	5	1	1	1	1	1
35	4	1	1	3	4	5	1	1	1	1	1
36	4	2	1	3	3	3	0	0	1	0	0
37	2	2	1	4	2	2	0	0	0	0	1
38	4	2	2	5	3	3	0	0	1	0	0

Appendix Figure I. 3: First phase studies - Part A nominal and ordinal data

User Session	UX1	UX2	UX3	UX4	UX5	UX6	UX7	UX8	UX9	UX10	UX11	UX12	UX13	UX14	UX15	UX16	UX17	UX18	UX19	UX20	UX21	UX22	UX23	UX24	UX25	UX26	UX27	UX28	UX29	UX30	UX31	UX32	UX33	UX34	UX35	UX36
1	3	2	4	2	2	1	2	2	2	3	4	4	4	2	2	2	2	2	4	3	2	3	2	5	1	1	1	3	2	2	2	3	3	3	4	2
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4	2	2	3	3	2	3	1	2	1	5	3	3	5	3	4	3	5	1	3	2	3	1	3	2	1	1	3	3	1	1	2	3	2	2	2	1
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16	3	4	3	4	4	1	2	2	4	5	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	4	1	1	1	3	3	2	4	4	2	2	4	4
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33	2	1	1	2	1	1	1	1	2	3	5	5	5	2	1	1	3	2	1	2	1	3	2	2	1	1	1	3	1	2	2	1	2	1	5	1
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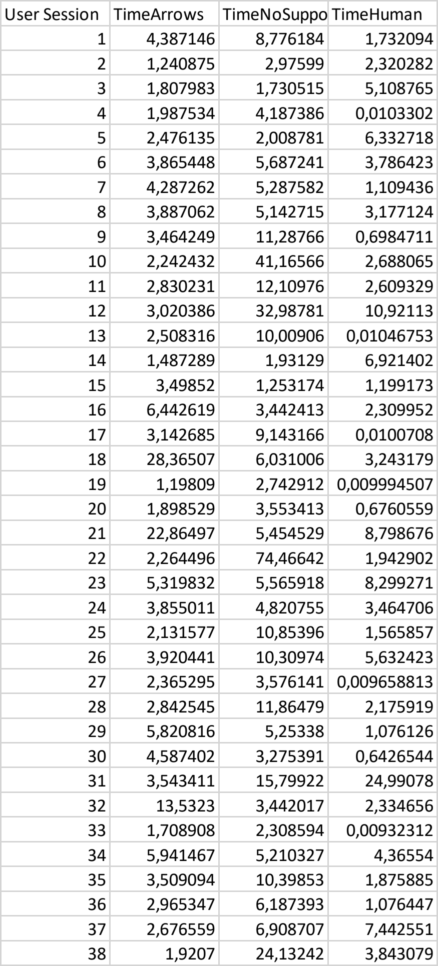
36	2	2	2	1	1	1	2	1	1	4	2	5	5	1	2	1	5	1	1	1	1	4	1	2	1	1	5	2	1	5	1	1	3	1	5	1
37	1	2	1	1	2	3	2	2	1	4	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	#NULL!	2	1	1	3	3	1	4	2	2	4	2	2	1
38	2	1	2	1	2	2	2	1	2	2	4	4	4	2	2	2	1	1	2	2	2	2	1	2	2	2	2	4	2	2	1	1	1	2	2	2

Appendix Figure I. 4: First phase studies - Part B ordinal data



User Session	TimeArrows	TimeNoSuppo	TimeHuman
1	4,387146	8,776184	1,732094
2	1,240875	2,97599	2,320282
3	1,807983	1,730515	5,108765
4	1,987534	4,187386	0,0103302
5	2,476135	2,008781	6,332718
6	3,865448	5,687241	3,786423
7	4,287262	5,287582	1,109436
8	3,887062	5,142715	3,177124
9	3,464249	11,28766	0,6984711
10	2,242432	41,16566	2,688065
11	2,830231	12,10976	2,609329
12	3,020386	32,98781	10,92113
13	2,508316	10,00906	0,01046753
14	1,487289	1,93129	6,921402
15	3,49852	1,253174	1,199173
16	6,442619	3,442413	2,309952
17	3,142685	9,143166	0,0100708
18	28,36507	6,031006	3,243179
19	1,19809	2,742912	0,009994507
20	1,898529	3,553413	0,6760559
21	22,86497	5,454529	8,798676
22	2,264496	74,46642	1,942902
23	5,319832	5,565918	8,299271
24	3,855011	4,820755	3,464706
25	2,131577	10,85396	1,565857
26	3,920441	10,30974	5,632423
27	2,365295	3,576141	0,009658813
28	2,842545	11,86479	2,175919
29	5,820816	5,25338	1,076126
30	4,587402	3,275391	0,6426544
31	3,543411	15,79922	24,99078
32	13,5323	3,442017	2,334656
33	1,708908	2,308594	0,00932312
34	5,941467	5,210327	4,36554
35	3,509094	10,39853	1,875885
36	2,965347	6,187393	1,076447
37	2,676559	6,908707	7,442551
38	1,9207	24,13242	3,843079

Appendix Figure I. 5: First phase studies - raw data - time

Appendix II – Second phase studies

II.1 Questionnaire

PART A - Demographic & General Questions

Age:

Gender:

○ Female ○ Male

Academic background/Profession:

How often do you tend to play digital games?

○ Everyday

○ Several times in a week

○ Once in a month

○ Every two-three months

○ I don’t usually play games

Have you ever had a VR immersive experience in the past?

○ Once

○ Up to five times

○ Up to ten times

○ Never

In case you had, was that a 360-video immersive experience?

○Yes ○ No

What’s your previous experience with a VR headset?

○ Never used it

○ I’ve used it once

○ I’ve used it a couple of times

○ I use it frequently

○ I have a wide experience of VR headsets
Please mark which ones you have used in the past. ○ Oculus VR ○ HTC Vive ○ Samsung Gear VR ○ Google Cardboard ○ Other

PART B Application V1

Scene 1:

The Radar map was useful in spotting the elements in the scene

Not at all 1 2 3 4 5 Very much so

The Timer element made me more focused

Not at all 1 2 3 4 5 Very much so

The Time element did it make you feel anxious?

Not at all 1 2 3 4 5 Very much so

The progress/feedback element was useful in accomplishing the task

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 2:

The Radar map was useful in spotting the elements in the scene

Not at all 1 2 3 4 5 Very much so

The progress/feedback element was useful in accomplishing the task

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 3:

The Radar map was useful in spotting the elements in the scene

Not at all 1 2 3 4 5 Very much so

The Timer element made me more focused

Not at all 1 2 3 4 5 Very much so

The Time element did it make you feel anxious?

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 4:

The Timer element made me more focused

Not at all 1 2 3 4 5 Very much so

The Time element did it make you feel anxious?

Not at all 1 2 3 4 5 Very much so

The progress/feedback element was useful in accomplishing the task

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 5:

The Radar map was useful in spotting the elements in the scene

Not at all 1 2 3 4 5 Very much so

The Timer element made me more focused

Not at all 1 2 3 4 5 Very much so

The Time element did it make you feel anxious?

Not at all 1 2 3 4 5 Very much so

The progress/feedback element was useful in accomplishing the task

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 6:

The Radar map was useful in spotting the elements in the scene

Not at all 1 2 3 4 5 Very much so

The progress/feedback element was useful in accomplishing the task

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 7:

The Radar map was useful in spotting the elements in the scene

Not at all 1 2 3 4 5 Very much so

The Timer element made me more focused

Not at all 1 2 3 4 5 Very much so

The Time element did it make you feel anxious?

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 8:

The Timer element made me more focused

Not at all 1 2 3 4 5 Very much so

The Time element did it make you feel anxious?

Not at all 1 2 3 4 5 Very much so

The progress/feedback element was useful in accomplishing the task

Not at all 1 2 3 4 5 Very much so

Did you find any of the UI (map, time, progress bar) elements distractive?

Did the UI elements improve your virtual experience?

Not at all 1 2 3 4 5 Very much so

Was is easy to spot the objects you were looking to find in the virtual scene?

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Which one you found that helped you more in accomplishing your task (efficient)?

○ Non-diegetic ○ Diegetic

Which one you found that was not distractive (not on the way) and thus more comfortable to use?

○ Non-diegetic ○ Diegetic

Which type of UI design approach you preferred (satisfaction)?

The ones that the UI was static (non-diegetic)?

The ones that the UI appeared as objects placed in the 3D scene (diegetic)?

○ Non-diegetic ○ Diegetic

Which type of UI design approach you felt that allowed to you to connect better with the scene (immersion)?

The ones that the UI was static?

The ones that the UI appeared as objects placed in the 3D scene?

○ Non-diegetic ○ Diegetic

PART B - Application V2

Scene 3:

Did you feel more connected with the virtual environment when playing the scene with the "spot the correct circled element"?

Not at all 1 2 3 4 5 Very much so

Did you feel like missing guidance of where to look, how many items you had to find (UI informative elements for navigation support and progress feedback in this scene?)

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 1&2:

It felt natural and comfortable to read the historical information

Not at all 1 2 3 4 5 Very much so

It felt more realistic to be provided with historical information by the Human Storyteller

Not at all 1 2 3 4 5 Very much so

It was easier to memorise the historical information when reading them than with the storyteller

Not at all 1 2 3 4 5 Very much so

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

Scene 4&5:

I felt I should turn to look where the actor was looking

Strongly agree 1 2 3 4 5 Strongly disagree

I felt I should turn to look where the arrows pointed

Strongly agree 1 2 3 4 5 Strongly disagree

I felt more natural to be guided by an actor than by graphics

Strongly agree 1 2 3 4 5 Strongly disagree

Did you feel you fully explored the 360-scene?

Not at all 1 2 3 4 5 Very much so

PART C - IMMERSIVE EXPERIENCE QUESTIONNAIRE

1. **To what extent did the VE hold your attention?**
   Not at all 1 2 3 4 5 A lot
2. **To what extent did you feel you were focused on the activity?**
   Not at all 1 2 3 4 5 A lot
3. **To what extent did you lose track of time?**
   Not at all 1 2 3 4 5 A lot
4. **To what extent did you feel consciously aware of being in the real world whilst playing?**
   Not at all 1 2 3 4 5 Very much so
5. **To what extent did you forget about your everyday concerns?**
   Not at all 1 2 3 4 5 A lot
6. **To what extent were you aware of yourself in your surroundings?**
   Not at all 1 2 3 4 5 Very aware
7. **To what extent did you notice events taking place around you?**
   Not at all 1 2 3 4 5 A lot

8. **Did you feel the urge at any point to stop playing and see what was happening around you?**
   Not at all 1 2 3 4 5 Very much so
9. **To what extent did you feel that you were interacting with the VE?**
   Not at all 1 2 3 4 5 Very much so
10. **To what extent did you feel as though you were separated from your real-world environment?**
    Not at all 1 2 3 4 5 Very much so
11. **To what extent did you feel that the game was something you were experiencing, rather than something you were just doing?**
    Not at all 1 2 3 4 5 Very much so
12. **To what extent was your sense of being in the game environment stronger than your sense of being in the real world?**
    Not at all 1 2 3 4 5 Very much so
13. **Were there any times during the game in which you just wanted to give up?**
    Not at all 1 2 3 4 5 A lot
14. **How much would you say you enjoyed playing the game?**
    Not at all 1 2 3 4 5 A lot
15. **Were you disappointed that this virtual experience was over?**
    Not at all 1 2 3 4 5 Very much so
16. **Would you like to have a similar virtual experience in the future?**
    Definitely not 1 2 3 4 5 Definitely yes
17. **I felt tired during my experience in this virtual environment**
    Not at all 1 2 3 4 5 Very much so
18. **I felt dizzy during my experience in this virtual environment**

Not at all 1 2 3 4 5 Very much so

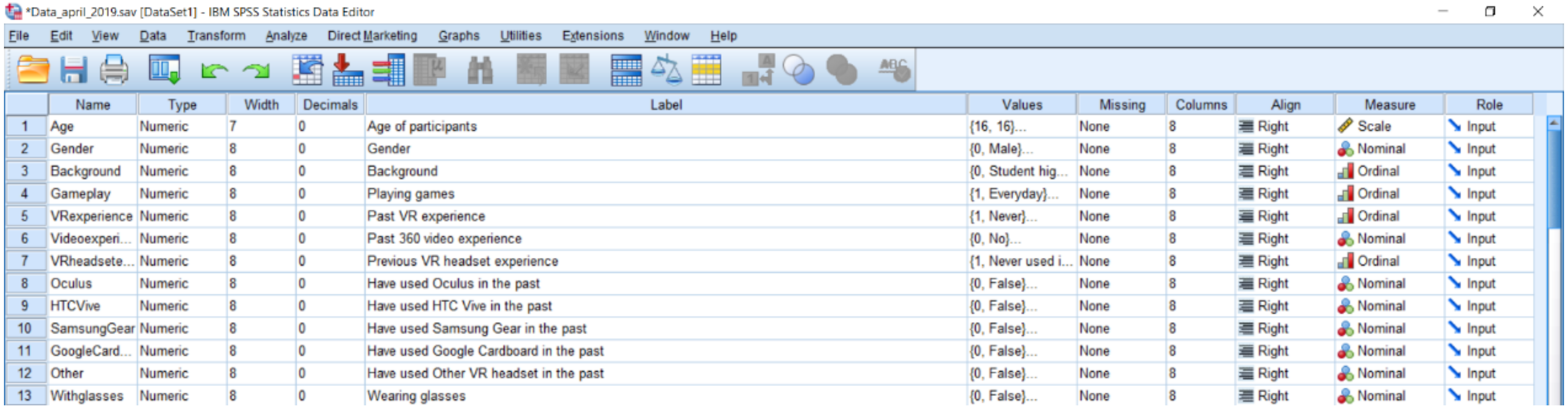
19. **I felt that I had control of my experience**
Not at all 1 2 3 4 5 Very much so

Which scene /What elements made you feel you had no control (if any)?

20. **I would like to spend more time in the virtual environment**
Definitely not 1 2 3 4 5 Definitely yes

21. **I quickly adjusted to the virtual experience**
Not at all 1 2 3 4 5 Very much so

II.2 Variables



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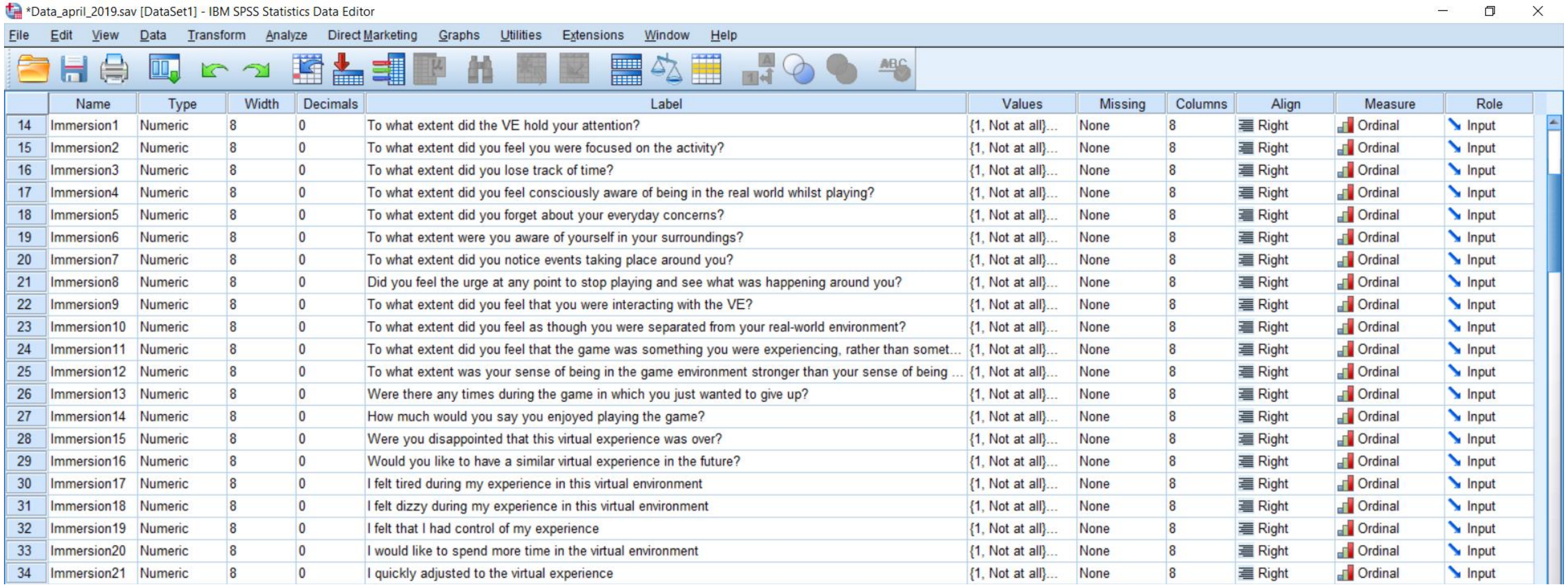
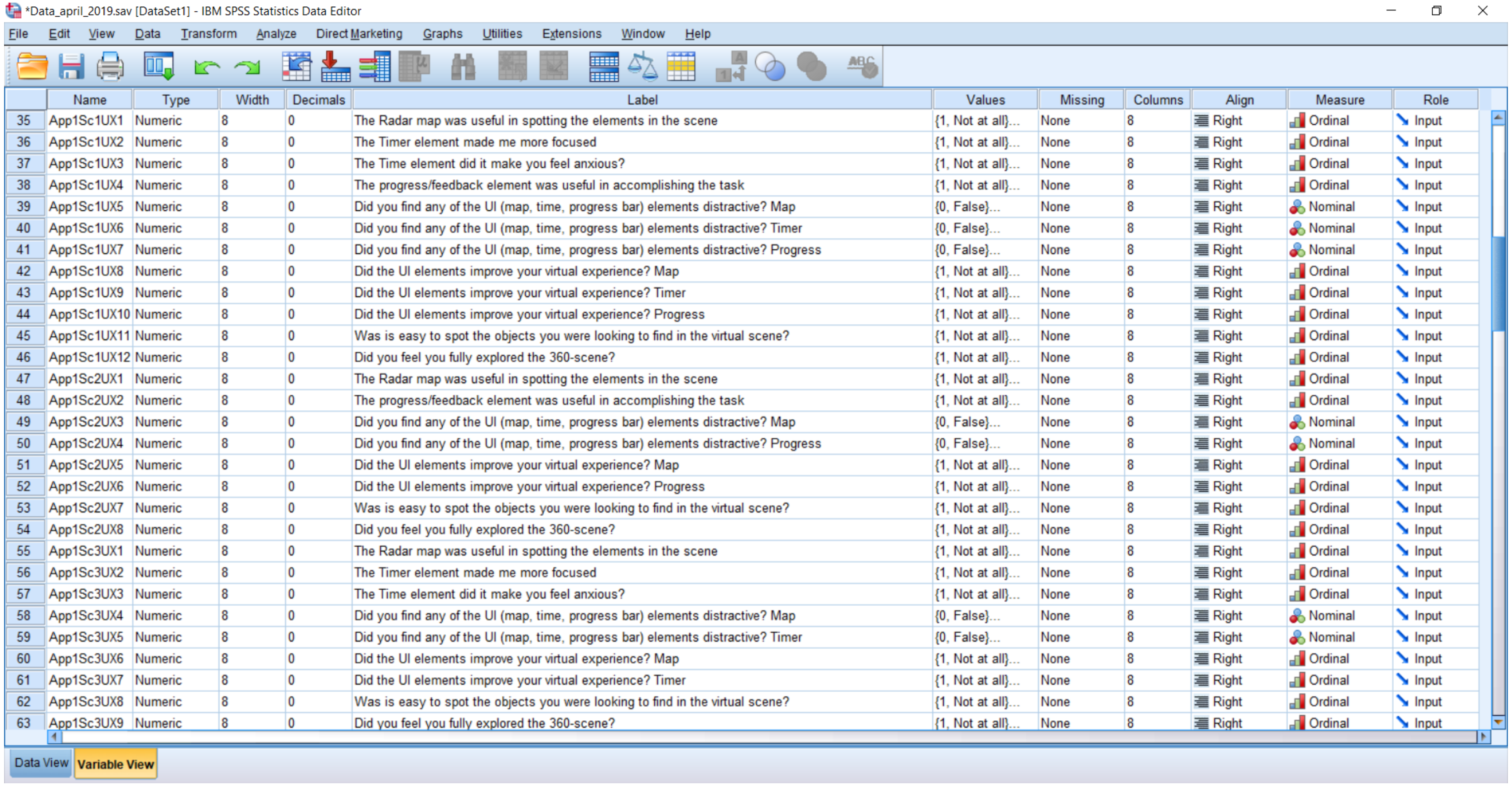
2	Gender	Numeric	8	0	Gender	{0, Male}...	None	8	Right	Nominal	Input
3	Background	Numeric	8	0	Background	{0, Student hig...	None	8	Right	Ordinal	Input
4	Gameplay	Numeric	8	0	Playing games	{1, Everyday}...	None	8	Right	Ordinal	Input
5	VRexperience	Numeric	8	0	Past VR experience	{1, Never}...	None	8	Right	Ordinal	Input
6	Videoexperi...	Numeric	8	0	Past 360 video experience	{0, No}...	None	8	Right	Nominal	Input
7	VRheadsete...	Numeric	8	0	Previous VR headset experience	{1, Never used i...	None	8	Right	Ordinal	Input
8	Oculus	Numeric	8	0	Have used Oculus in the past	{0, False}...	None	8	Right	Nominal	Input
9	HTCVive	Numeric	8	0	Have used HTC Vive in the past	{0, False}...	None	8	Right	Nominal	Input
10	SamsungGear	Numeric	8	0	Have used Samsung Gear in the past	{0, False}...	None	8	Right	Nominal	Input
11	GoogleCard...	Numeric	8	0	Have used Google Cardboard in the past	{0, False}...	None	8	Right	Nominal	Input
12	Other	Numeric	8	0	Have used Other VR headset in the past	{0, False}...	None	8	Right	Nominal	Input
13	Withglasses	Numeric	8	0	Wearing glasses	{0, False}...	None	8	Right	Nominal	Input

Appendix Figure II. 1: Second phase studies - Part A of the questionnaire variables



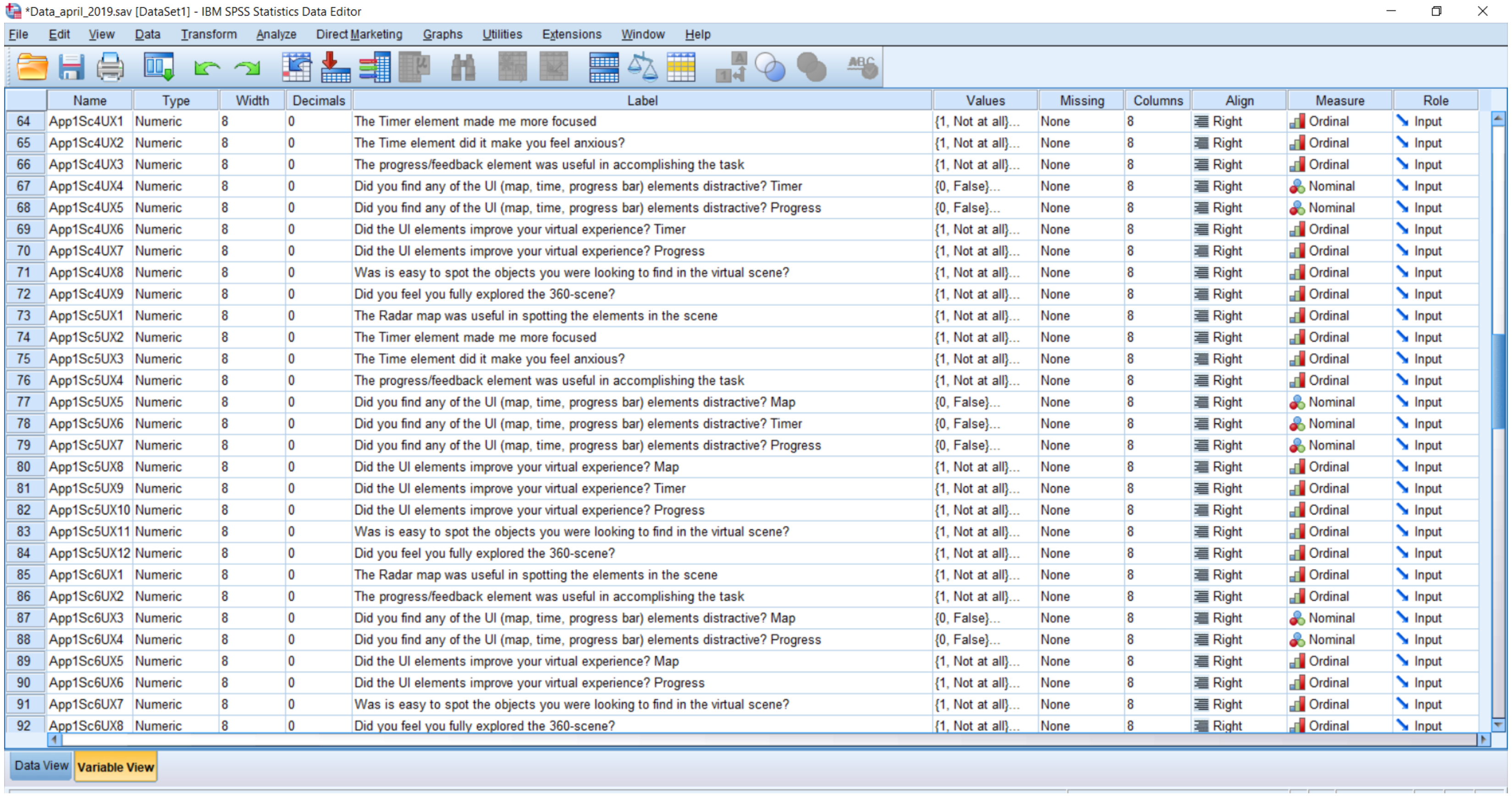
	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
14	Immersion1	Numeric	8	0	To what extent did the VE hold your attention?	{1, Not at all}...	None	8	Right	Ordinal	Input
15	Immersion2	Numeric	8	0	To what extent did you feel you were focused on the activity?	{1, Not at all}...	None	8	Right	Ordinal	Input
16	Immersion3	Numeric	8	0	To what extent did you lose track of time?	{1, Not at all}...	None	8	Right	Ordinal	Input
17	Immersion4	Numeric	8	0	To what extent did you feel consciously aware of being in the real world whilst playing?	{1, Not at all}...	None	8	Right	Ordinal	Input
18	Immersion5	Numeric	8	0	To what extent did you forget about your everyday concerns?	{1, Not at all}...	None	8	Right	Ordinal	Input
19	Immersion6	Numeric	8	0	To what extent were you aware of yourself in your surroundings?	{1, Not at all}...	None	8	Right	Ordinal	Input
20	Immersion7	Numeric	8	0	To what extent did you notice events taking place around you?	{1, Not at all}...	None	8	Right	Ordinal	Input
21	Immersion8	Numeric	8	0	Did you feel the urge at any point to stop playing and see what was happening around you?	{1, Not at all}...	None	8	Right	Ordinal	Input
22	Immersion9	Numeric	8	0	To what extent did you feel that you were interacting with the VE?	{1, Not at all}...	None	8	Right	Ordinal	Input
23	Immersion10	Numeric	8	0	To what extent did you feel as though you were separated from your real-world environment?	{1, Not at all}...	None	8	Right	Ordinal	Input
24	Immersion11	Numeric	8	0	To what extent did you feel that the game was something you were experiencing, rather than somet...	{1, Not at all}...	None	8	Right	Ordinal	Input
25	Immersion12	Numeric	8	0	To what extent was your sense of being in the game environment stronger than your sense of being ...	{1, Not at all}...	None	8	Right	Ordinal	Input
26	Immersion13	Numeric	8	0	Were there any times during the game in which you just wanted to give up?	{1, Not at all}...	None	8	Right	Ordinal	Input
27	Immersion14	Numeric	8	0	How much would you say you enjoyed playing the game?	{1, Not at all}...	None	8	Right	Ordinal	Input
28	Immersion15	Numeric	8	0	Were you disappointed that this virtual experience was over?	{1, Not at all}...	None	8	Right	Ordinal	Input
29	Immersion16	Numeric	8	0	Would you like to have a similar virtual experience in the future?	{1, Not at all}...	None	8	Right	Ordinal	Input
30	Immersion17	Numeric	8	0	I felt tired during my experience in this virtual environment	{1, Not at all}...	None	8	Right	Ordinal	Input
31	Immersion18	Numeric	8	0	I felt dizzy during my experience in this virtual environment	{1, Not at all}...	None	8	Right	Ordinal	Input
32	Immersion19	Numeric	8	0	I felt that I had control of my experience	{1, Not at all}...	None	8	Right	Ordinal	Input
33	Immersion20	Numeric	8	0	I would like to spend more time in the virtual environment	{1, Not at all}...	None	8	Right	Ordinal	Input
34	Immersion21	Numeric	8	0	I quickly adjusted to the virtual experience	{1, Not at all}...	None	8	Right	Ordinal	Input

Appendix Figure II. 2 : Second phase studies - Part C of the questionnaire variables



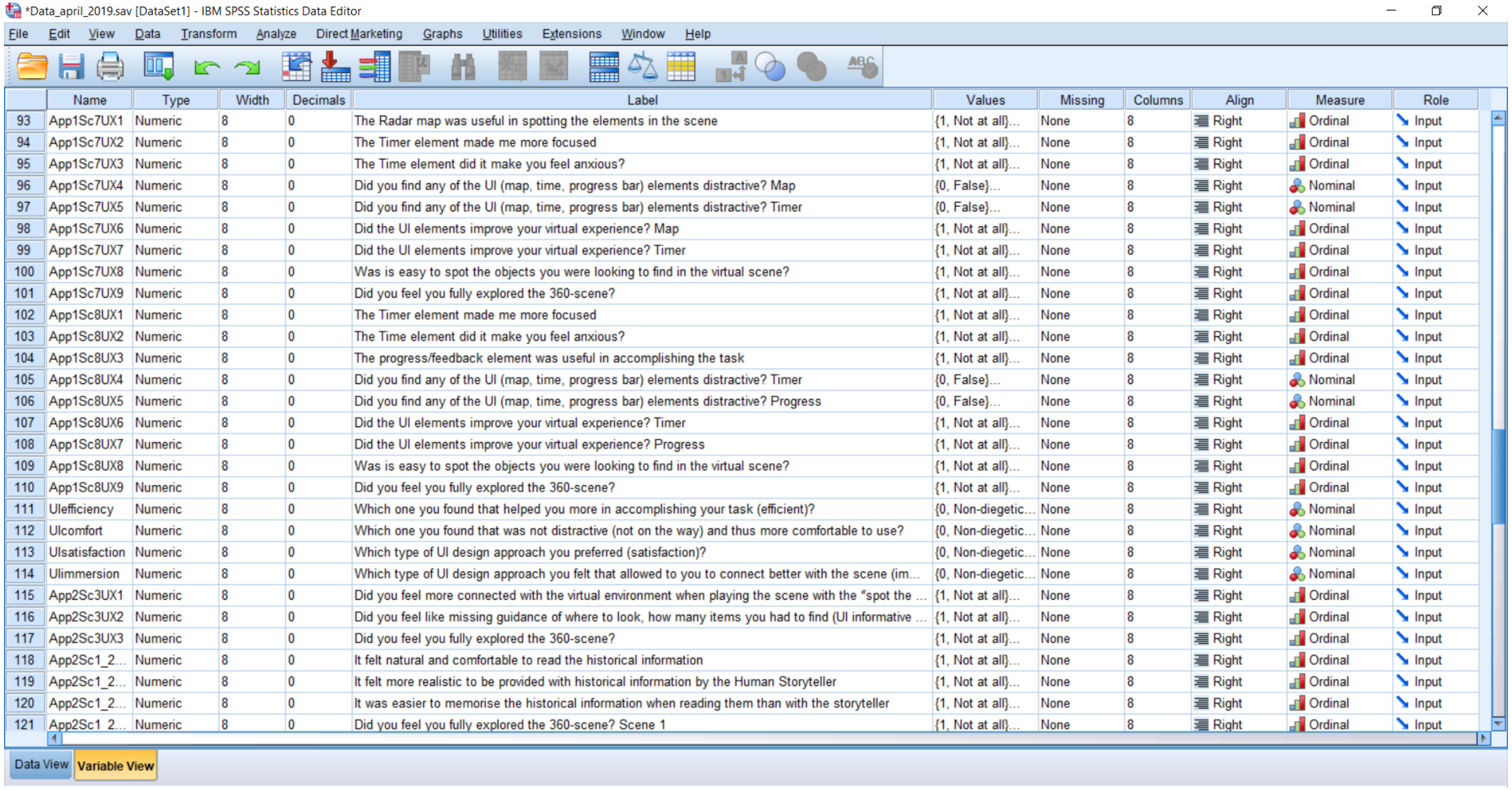
	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
35	App1Sc1UX1	Numeric	8	0	The Radar map was useful in spotting the elements in the scene	{1, Not at all}...	None	8	Right	Ordinal	Input
36	App1Sc1UX2	Numeric	8	0	The Timer element made me more focused	{1, Not at all}...	None	8	Right	Ordinal	Input
37	App1Sc1UX3	Numeric	8	0	The Time element did it make you feel anxious?	{1, Not at all}...	None	8	Right	Ordinal	Input
38	App1Sc1UX4	Numeric	8	0	The progress/feedback element was useful in accomplishing the task	{1, Not at all}...	None	8	Right	Ordinal	Input
39	App1Sc1UX5	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Map	{0, False}...	None	8	Right	Nominal	Input
40	App1Sc1UX6	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Timer	{0, False}...	None	8	Right	Nominal	Input
41	App1Sc1UX7	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Progress	{0, False}...	None	8	Right	Nominal	Input
42	App1Sc1UX8	Numeric	8	0	Did the UI elements improve your virtual experience? Map	{1, Not at all}...	None	8	Right	Ordinal	Input
43	App1Sc1UX9	Numeric	8	0	Did the UI elements improve your virtual experience? Timer	{1, Not at all}...	None	8	Right	Ordinal	Input
44	App1Sc1UX10	Numeric	8	0	Did the UI elements improve your virtual experience? Progress	{1, Not at all}...	None	8	Right	Ordinal	Input
45	App1Sc1UX11	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
46	App1Sc1UX12	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
47	App1Sc2UX1	Numeric	8	0	The Radar map was useful in spotting the elements in the scene	{1, Not at all}...	None	8	Right	Ordinal	Input
48	App1Sc2UX2	Numeric	8	0	The progress/feedback element was useful in accomplishing the task	{1, Not at all}...	None	8	Right	Ordinal	Input
49	App1Sc2UX3	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Map	{0, False}...	None	8	Right	Nominal	Input
50	App1Sc2UX4	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Progress	{0, False}...	None	8	Right	Nominal	Input
51	App1Sc2UX5	Numeric	8	0	Did the UI elements improve your virtual experience? Map	{1, Not at all}...	None	8	Right	Ordinal	Input
52	App1Sc2UX6	Numeric	8	0	Did the UI elements improve your virtual experience? Progress	{1, Not at all}...	None	8	Right	Ordinal	Input
53	App1Sc2UX7	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
54	App1Sc2UX8	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
55	App1Sc3UX1	Numeric	8	0	The Radar map was useful in spotting the elements in the scene	{1, Not at all}...	None	8	Right	Ordinal	Input
56	App1Sc3UX2	Numeric	8	0	The Timer element made me more focused	{1, Not at all}...	None	8	Right	Ordinal	Input
57	App1Sc3UX3	Numeric	8	0	The Time element did it make you feel anxious?	{1, Not at all}...	None	8	Right	Ordinal	Input
58	App1Sc3UX4	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Map	{0, False}...	None	8	Right	Nominal	Input
59	App1Sc3UX5	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Timer	{0, False}...	None	8	Right	Nominal	Input
60	App1Sc3UX6	Numeric	8	0	Did the UI elements improve your virtual experience? Map	{1, Not at all}...	None	8	Right	Ordinal	Input
61	App1Sc3UX7	Numeric	8	0	Did the UI elements improve your virtual experience? Timer	{1, Not at all}...	None	8	Right	Ordinal	Input
62	App1Sc3UX8	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
63	App1Sc3UX9	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input

Appendix Figure II. 3: Second phase studies - Part B of the questionnaire variables (a)



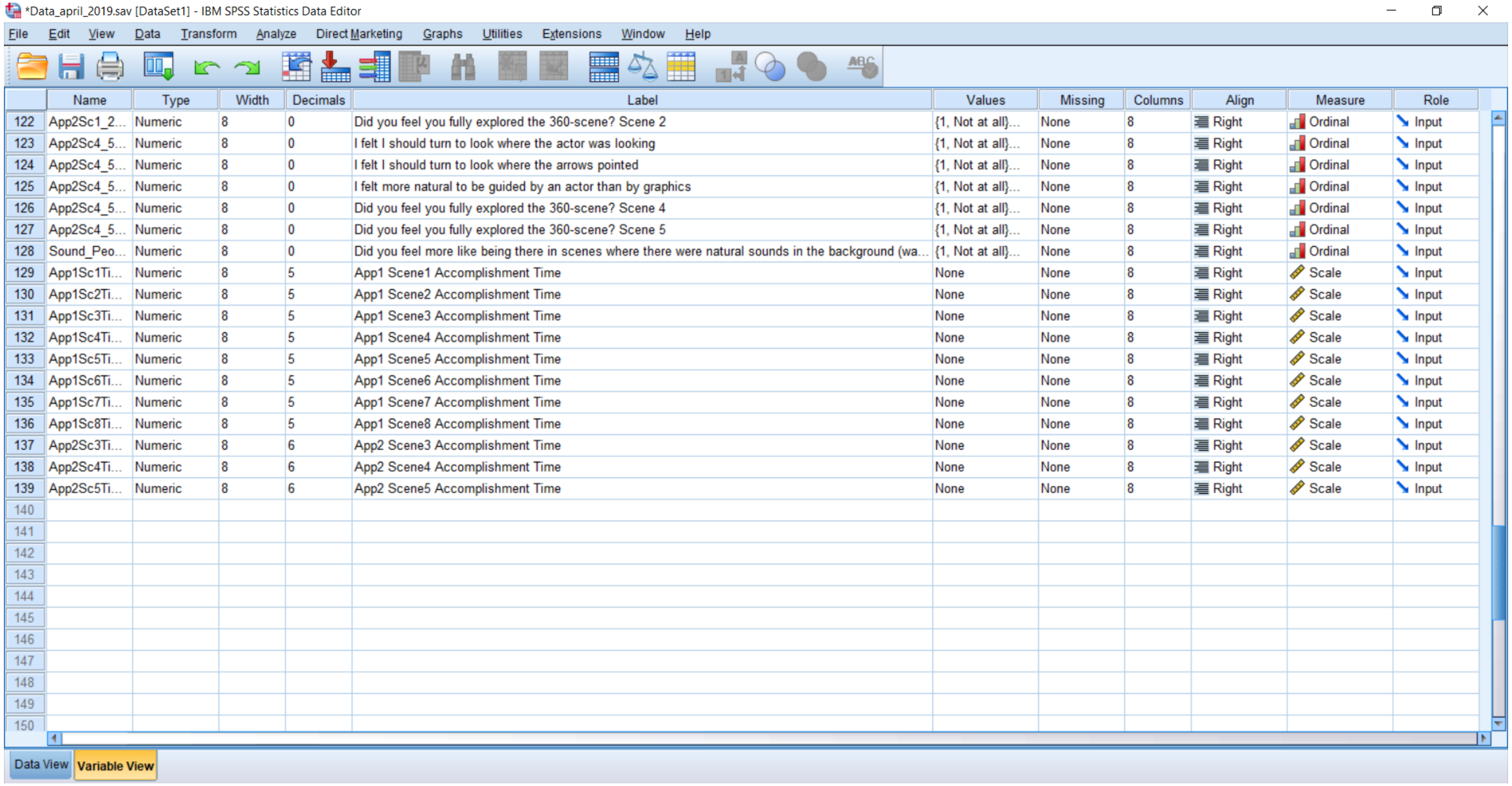
	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
64	App1Sc4UX1	Numeric	8	0	The Timer element made me more focused	{1, Not at all}...	None	8	Right	Ordinal	Input
65	App1Sc4UX2	Numeric	8	0	The Time element did it make you feel anxious?	{1, Not at all}...	None	8	Right	Ordinal	Input
66	App1Sc4UX3	Numeric	8	0	The progress/feedback element was useful in accomplishing the task	{1, Not at all}...	None	8	Right	Ordinal	Input
67	App1Sc4UX4	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Timer	{0, False}...	None	8	Right	Nominal	Input
68	App1Sc4UX5	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Progress	{0, False}...	None	8	Right	Nominal	Input
69	App1Sc4UX6	Numeric	8	0	Did the UI elements improve your virtual experience? Timer	{1, Not at all}...	None	8	Right	Ordinal	Input
70	App1Sc4UX7	Numeric	8	0	Did the UI elements improve your virtual experience? Progress	{1, Not at all}...	None	8	Right	Ordinal	Input
71	App1Sc4UX8	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
72	App1Sc4UX9	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
73	App1Sc5UX1	Numeric	8	0	The Radar map was useful in spotting the elements in the scene	{1, Not at all}...	None	8	Right	Ordinal	Input
74	App1Sc5UX2	Numeric	8	0	The Timer element made me more focused	{1, Not at all}...	None	8	Right	Ordinal	Input
75	App1Sc5UX3	Numeric	8	0	The Time element did it make you feel anxious?	{1, Not at all}...	None	8	Right	Ordinal	Input
76	App1Sc5UX4	Numeric	8	0	The progress/feedback element was useful in accomplishing the task	{1, Not at all}...	None	8	Right	Ordinal	Input
77	App1Sc5UX5	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Map	{0, False}...	None	8	Right	Nominal	Input
78	App1Sc5UX6	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Timer	{0, False}...	None	8	Right	Nominal	Input
79	App1Sc5UX7	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Progress	{0, False}...	None	8	Right	Nominal	Input
80	App1Sc5UX8	Numeric	8	0	Did the UI elements improve your virtual experience? Map	{1, Not at all}...	None	8	Right	Ordinal	Input
81	App1Sc5UX9	Numeric	8	0	Did the UI elements improve your virtual experience? Timer	{1, Not at all}...	None	8	Right	Ordinal	Input
82	App1Sc5UX10	Numeric	8	0	Did the UI elements improve your virtual experience? Progress	{1, Not at all}...	None	8	Right	Ordinal	Input
83	App1Sc5UX11	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
84	App1Sc5UX12	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
85	App1Sc6UX1	Numeric	8	0	The Radar map was useful in spotting the elements in the scene	{1, Not at all}...	None	8	Right	Ordinal	Input
86	App1Sc6UX2	Numeric	8	0	The progress/feedback element was useful in accomplishing the task	{1, Not at all}...	None	8	Right	Ordinal	Input
87	App1Sc6UX3	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Map	{0, False}...	None	8	Right	Nominal	Input
88	App1Sc6UX4	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Progress	{0, False}...	None	8	Right	Nominal	Input
89	App1Sc6UX5	Numeric	8	0	Did the UI elements improve your virtual experience? Map	{1, Not at all}...	None	8	Right	Ordinal	Input
90	App1Sc6UX6	Numeric	8	0	Did the UI elements improve your virtual experience? Progress	{1, Not at all}...	None	8	Right	Ordinal	Input
91	App1Sc6UX7	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
92	App1Sc6UX8	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input

Appendix Figure II. 4: Second phase studies - Part B of the questionnaire variables (b)



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
93	App1Sc7UX1	Numeric	8	0	The Radar map was useful in spotting the elements in the scene	{1, Not at all}...	None	8	Right	Ordinal	Input
94	App1Sc7UX2	Numeric	8	0	The Timer element made me more focused	{1, Not at all}...	None	8	Right	Ordinal	Input
95	App1Sc7UX3	Numeric	8	0	The Time element did it make you feel anxious?	{1, Not at all}...	None	8	Right	Ordinal	Input
96	App1Sc7UX4	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Map	{0, False}...	None	8	Right	Nominal	Input
97	App1Sc7UX5	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Timer	{0, False}...	None	8	Right	Nominal	Input
98	App1Sc7UX6	Numeric	8	0	Did the UI elements improve your virtual experience? Map	{1, Not at all}...	None	8	Right	Ordinal	Input
99	App1Sc7UX7	Numeric	8	0	Did the UI elements improve your virtual experience? Timer	{1, Not at all}...	None	8	Right	Ordinal	Input
100	App1Sc7UX8	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
101	App1Sc7UX9	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
102	App1Sc8UX1	Numeric	8	0	The Timer element made me more focused	{1, Not at all}...	None	8	Right	Ordinal	Input
103	App1Sc8UX2	Numeric	8	0	The Time element did it make you feel anxious?	{1, Not at all}...	None	8	Right	Ordinal	Input
104	App1Sc8UX3	Numeric	8	0	The progress/feedback element was useful in accomplishing the task	{1, Not at all}...	None	8	Right	Ordinal	Input
105	App1Sc8UX4	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Timer	{0, False}...	None	8	Right	Nominal	Input
106	App1Sc8UX5	Numeric	8	0	Did you find any of the UI (map, time, progress bar) elements distractive? Progress	{0, False}...	None	8	Right	Nominal	Input
107	App1Sc8UX6	Numeric	8	0	Did the UI elements improve your virtual experience? Timer	{1, Not at all}...	None	8	Right	Ordinal	Input
108	App1Sc8UX7	Numeric	8	0	Did the UI elements improve your virtual experience? Progress	{1, Not at all}...	None	8	Right	Ordinal	Input
109	App1Sc8UX8	Numeric	8	0	Was is easy to spot the objects you were looking to find in the virtual scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
110	App1Sc8UX9	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
111	UIefficiency	Numeric	8	0	Which one you found that helped you more in accomplishing your task (efficient)?	{0, Non-diegetic...	None	8	Right	Nominal	Input
112	UIcomfort	Numeric	8	0	Which one you found that was not distractive (not on the way) and thus more comfortable to use?	{0, Non-diegetic...	None	8	Right	Nominal	Input
113	UIsatisfaction	Numeric	8	0	Which type of UI design approach you preferred (satisfaction)?	{0, Non-diegetic...	None	8	Right	Nominal	Input
114	UIimmersion	Numeric	8	0	Which type of UI design approach you felt that allowed to you to connect better with the scene (im...	{0, Non-diegetic...	None	8	Right	Nominal	Input
115	App2Sc3UX1	Numeric	8	0	Did you feel more connected with the virtual environment when playing the scene with the "spot the ...	{1, Not at all}...	None	8	Right	Ordinal	Input
116	App2Sc3UX2	Numeric	8	0	Did you feel like missing guidance of where to look, how many items you had to find (UI informative ...	{1, Not at all}...	None	8	Right	Ordinal	Input
117	App2Sc3UX3	Numeric	8	0	Did you feel you fully explored the 360-scene?	{1, Not at all}...	None	8	Right	Ordinal	Input
118	App2Sc1_2...	Numeric	8	0	It felt natural and comfortable to read the historical information	{1, Not at all}...	None	8	Right	Ordinal	Input
119	App2Sc1_2...	Numeric	8	0	It felt more realistic to be provided with historical information by the Human Storyteller	{1, Not at all}...	None	8	Right	Ordinal	Input
120	App2Sc1_2...	Numeric	8	0	It was easier to memorise the historical information when reading them than with the storyteller	{1, Not at all}...	None	8	Right	Ordinal	Input
121	App2Sc1_2...	Numeric	8	0	Did you feel you fully explored the 360-scene? Scene 1	{1, Not at all}...	None	8	Right	Ordinal	Input

Appendix Figure II. 5: Second phase studies - Part B of the questionnaire variables (c)



*Data_april_2019.sav [DataSet1] - IBM SPSS Statistics Data Editor

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
122	App2Sc1_2...	Numeric	8	0	Did you feel you fully explored the 360-scene? Scene 2	{1, Not at all}...	None	8	Right	Ordinal	Input
123	App2Sc4_5...	Numeric	8	0	I felt I should turn to look where the actor was looking	{1, Not at all}...	None	8	Right	Ordinal	Input
124	App2Sc4_5...	Numeric	8	0	I felt I should turn to look where the arrows pointed	{1, Not at all}...	None	8	Right	Ordinal	Input
125	App2Sc4_5...	Numeric	8	0	I felt more natural to be guided by an actor than by graphics	{1, Not at all}...	None	8	Right	Ordinal	Input
126	App2Sc4_5...	Numeric	8	0	Did you feel you fully explored the 360-scene? Scene 4	{1, Not at all}...	None	8	Right	Ordinal	Input
127	App2Sc4_5...	Numeric	8	0	Did you feel you fully explored the 360-scene? Scene 5	{1, Not at all}...	None	8	Right	Ordinal	Input
128	Sound_Peo...	Numeric	8	0	Did you feel more like being there in scenes where there were natural sounds in the background (wa...	{1, Not at all}...	None	8	Right	Ordinal	Input
129	App1Sc1Ti...	Numeric	8	5	App1 Scene1 Accomplishment Time	None	None	8	Right	Scale	Input
130	App1Sc2Ti...	Numeric	8	5	App1 Scene2 Accomplishment Time	None	None	8	Right	Scale	Input
131	App1Sc3Ti...	Numeric	8	5	App1 Scene3 Accomplishment Time	None	None	8	Right	Scale	Input
132	App1Sc4Ti...	Numeric	8	5	App1 Scene4 Accomplishment Time	None	None	8	Right	Scale	Input
133	App1Sc5Ti...	Numeric	8	5	App1 Scene5 Accomplishment Time	None	None	8	Right	Scale	Input
134	App1Sc6Ti...	Numeric	8	5	App1 Scene6 Accomplishment Time	None	None	8	Right	Scale	Input
135	App1Sc7Ti...	Numeric	8	5	App1 Scene7 Accomplishment Time	None	None	8	Right	Scale	Input
136	App1Sc8Ti...	Numeric	8	5	App1 Scene8 Accomplishment Time	None	None	8	Right	Scale	Input
137	App2Sc3Ti...	Numeric	8	6	App2 Scene3 Accomplishment Time	None	None	8	Right	Scale	Input
138	App2Sc4Ti...	Numeric	8	6	App2 Scene4 Accomplishment Time	None	None	8	Right	Scale	Input
139	App2Sc5Ti...	Numeric	8	6	App2 Scene5 Accomplishment Time	None	None	8	Right	Scale	Input
140											
141											
142											
143											
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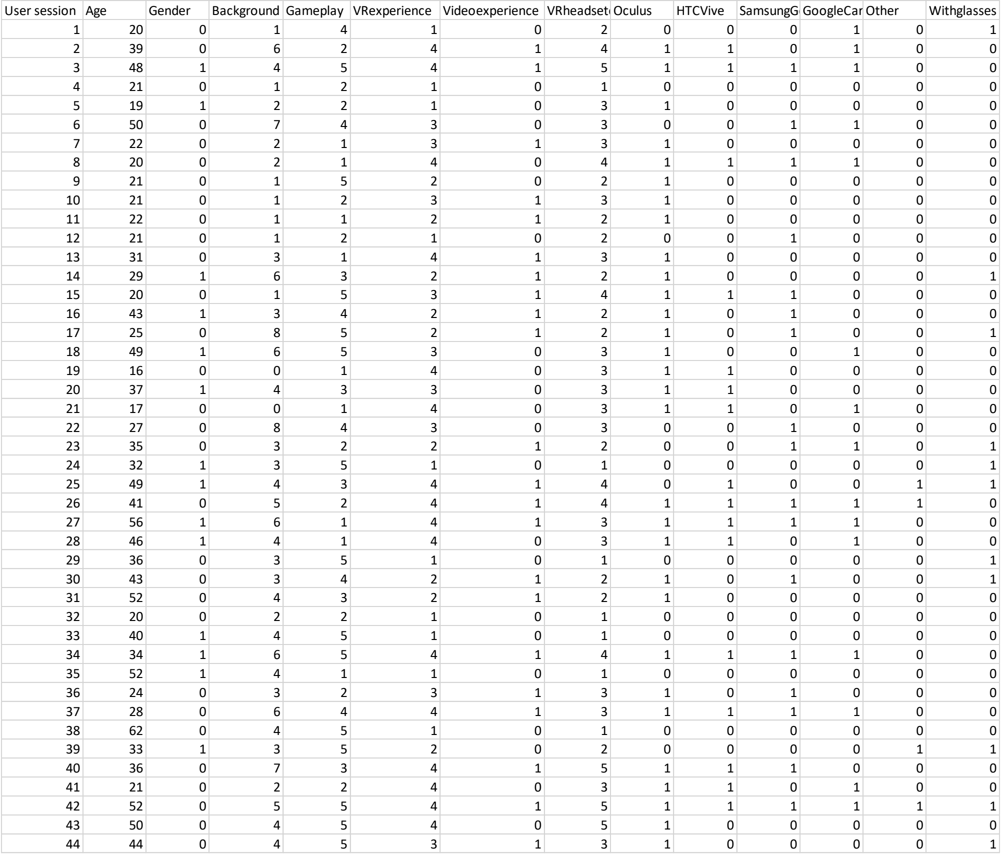
Appendix Figure II. 6: Second phase studies - Part B of the questionnaire variables (d) – log data variables

II.3 Data

The data from the Second phase studies are available for download in Excel form at:

https://drive.google.com/open?id=16MBFKy7hbMtbg1vPkHjpJTKhEFk9BnIt



User session	Age	Gender	Background	Gameplay	VRexperience	Videoexperience	VRheadset	Oculus	HTCVive	SamsungG	GoogleCar	Other	Withglasses
1	20	0	1	4	1	0	2	0	0	0	1	0	1
2	39	0	6	2	4	1	4	1	1	0	1	0	0
3	48	1	4	5	4	1	5	1	1	1	1	0	0
4	21	0	1	2	1	0	1	0	0	0	0	0	0
5	19	1	2	2	1	0	3	1	0	0	0	0	0
6	50	0	7	4	3	0	3	0	0	1	1	0	0
7	22	0	2	1	3	1	3	1	0	0	0	0	0
8	20	0	2	1	4	0	4	1	1	1	1	0	0
9	21	0	1	5	2	0	2	1	0	0	0	0	0
10	21	0	1	2	3	1	3	1	0	0	0	0	0
11	22	0	1	1	2	1	2	1	0	0	0	0	0
12	21	0	1	2	1	0	2	0	0	1	0	0	0
13	31	0	3	1	4	1	3	1	0	0	0	0	0
14	29	1	6	3	2	1	2	1	0	0	0	0	1
15	20	0	1	5	3	1	4	1	1	1	0	0	0
16	43	1	3	4	2	1	2	1	0	1	0	0	0
17	25	0	8	5	2	1	2	1	0	1	0	0	1
18	49	1	6	5	3	0	3	1	0	0	1	0	0
19	16	0	0	1	4	0	3	1	1	0	0	0	0
20	37	1	4	3	3	0	3	1	1	0	0	0	0
21	17	0	0	1	4	0	3	1	1	0	1	0	0
22	27	0	8	4	3	0	3	0	0	1	0	0	0
23	35	0	3	2	2	1	2	0	0	1	1	0	1
24	32	1	3	5	1	0	1	0	0	0	0	0	1
25	49	1	4	3	4	1	4	0	1	0	0	1	1
26	41	0	5	2	4	1	4	1	1	1	1	1	0
27	56	1	6	1	4	1	3	1	1	1	1	0	0
28	46	1	4	1	4	0	3	1	1	0	1	0	0
29	36	0	3	5	1	0	1	0	0	0	0	0	1
30	43	0	3	4	2	1	2	1	0	1	0	0	1
31	52	0	4	3	2	1	2	1	0	0	0	0	0
32	20	0	2	2	1	0	1	0	0	0	0	0	0
33	40	1	4	5	1	0	1	0	0	0	0	0	0
34	34	1	6	5	4	1	4	1	1	1	1	0	0
35	52	1	4	1	1	0	1	0	0	0	0	0	0
36	24	0	3	2	3	1	3	1	0	1	0	0	0
37	28	0	6	4	4	1	3	1	1	1	1	0	0
38	62	0	4	5	1	0	1	0	0	0	0	0	0
39	33	1	3	5	2	0	2	0	0	0	0	1	1
40	36	0	7	3	4	1	5	1	1	1	0	0	0
41	21	0	2	2	4	0	3	1	1	0	1	0	0
42	52	0	5	5	4	1	5	1	1	1	1	1	1
43	50	0	4	5	4	0	5	1	0	0	0	0	0
44	44	0	4	5	3	1	3	1	0	0	0	0	1

Appendix Figure II. 7: Second phase studies - Part A of the questionnaire data

User session	Immers1	Immers2	Immesr3	Immers4	Immers5	Immers6	Immers7	Immers8	Immers9	Immers10	Immers11	Immers12	Immers13	Immers14	Immers5	Immers16	Immers17	Immers18	Immers19	Immers20	Immers21
1	4	4	4	4	5	4	2	3	4	3	2	4	1	4	3	4	3	1	4	4	5
2	4	5	4	3	4	4	4	3	3	4	5	3	2	4	3	4	5	4	4	4	3
3	5	5	5	4	5	4	4	1	#NULL!	5	5	5	1	4	4	5	2	1	4	5	5
4	5	5	3	2	5	1	2	1	5	5	2	2	1	4	4	5	1	3	5	4	5
5	4	4	4	2	1	3	2	3	3	4	4	3	3	3	3	4	4	4	3	4	3
6	5	5	3	3	4	5	4	1	4	1	2	2	1	4	3	5	3	1	2	5	5
7	5	4	5	2	3	5	3	2	5	3	4	3	1	4	3	4	3	1	5	4	5
8	5	5	2	5	5	5	5	4	5	5	5	5	1	5	5	5	1	1	5	5	5
9	4	4	5	5	4	4	3	4	3	5	4	3	3	4	3	5	4	4	4	4	5
10	2	3	2	3	3	2	1	3	4	4	4	3	4	3	2	2	4	1	4	2	3
11	4	4	1	2	3	3	4	4	4	3	2	3	1	4	3	4	2	4	4	2	5
12	4	4	5	3	5	3	2	2	4	4	3	4	1	4	2	5	3	2	3	4	5
13	4	4	2	4	2	3	4	1	3	1	2	2	1	2	1	3	4	1	3	3	5
14	4	3	1	3	4	5	4	1	3	4	5	4	1	1	1	5	4	3	3	4	4
15	4	4	3	4	5	3	2	5	4	4	3	3	2	4	3	3	4	2	3	2	4
16	5	5	5	1	5	5	4	5	4	4	5	5	1	5	2	5	1	1	4	5	4
17	5	5	5	1	5	1	1	1	5	5	5	4	2	5	3	5	2	3	5	5	3
18	5	5	4	4	5	4	4	2	4	4	4	3	1	5	4	5	1	1	4	5	5
19	4	4	3	2	2	3	3	1	4	3	2	2	1	3	3	3	2	1	3	4	4
20	5	5	3	4	4	4	3	1	4	3	4	4	1	4	2	4	4	1	4	4	4
21	4	5	2	3	1	3	4	2	3	2	3	2	1	3	3	3	1	1	4	3	5
22	5	5	5	4	5	3	1	#NULL!	1	5	4	4	1	4	4	5	1	1	5	5	4
23	5	5	5	4	5	4	4	1	5	5	4	3	1	5	1	5	3	4	5	5	5
24	4	4	5	4	2	5	2	1	4	3	4	3	1	4	5	5	3	1	5	5	4
25	5	5	1	2	4	4	3	1	4	3	3	3	1	4	3	4	4	2	5	4	5
26	4	3	1	3	4	3	4	2	4	3	4	4	4	2	1	1	3	1	4	4	5
27	5	5	5	5	5	5	3	1	5	3	2	5	2	5	2	5	1	1	5	3	5
28	5	5	5	4	5	1	1	1	5	5	1	5	1	5	1	5	1	1	5	5	5
29	5	5	5	5	5	4	3	1	5	4	4	5	3	4	1	2	2	2	5	1	4
30	5	5	5	3	5	2	2	2	4	5	3	4	1	4	2	5	1	1	4	3	4
31	5	5	4	4	4	3	3	2	4	4	4	3	1	5	4	5	1	1	4	5	5
32	4	5	3	3	2	2	2	3	4	4	4	2	1	3	3	4	1	1	4	3	3
33	5	5	4	1	5	5	2	2	5	5	5	5	1	5	1	5	1	1	5	5	5
34	3	4	5	3	4	2	3	4	2	3	3	2	3	3	1	3	1	4	2	4	4
35	3	4	1	5	1	3	2	5	2	1	1	1	1	3	1	4	3	4	1	4	4
36	5	4	5	2	5	2	2	1	4	3	4	3	1	4	4	5	4	1	4	5	4
37	4	5	5	4	1	4	2	2	5	3	2	2	1	3	3	3	2	1	3	3	5
38	5	5	2	2	2	4	5	1	4	2	3	3	1	4	3	5	3	1	2	3	3
39	5	5	3	3	5	1	1	1	5	3	5	5	1	5	2	4	4	3	5	2	5
40	4	5	5	5	3	4	4	1	5	3	5	4	1	3	2	5	2	4	4	3	5
41	4	4	5	1	4	3	2	1	3	5	3	3	1	3	1	3	1	1	5	4	5
42	4	5	4	4	4	4	3	3	4	4	4	4	3	4	3	4	3	4	4	3	4
43	4	3	4	1	1	2	3	3	5	4	3	1	3	4	1	1	4	5	3	1	5
44	5	5	5	3	5	3	2	1	3	5	4	5	2	5	4	5	4	4	5	5	3

Appendix Figure II. 8: Second phase studies - Part C of the questionnaire data

User session	A1S1UX1	A1S1UX2	A1S1UX3	A1S1UX4	A1S1UX5	A1S1UX6	A1S1UX7	A1S1UX8	A1S1UX9	A1S1UX10	A1S1UX11	A1S1UX12	A1S2UX1	A1S2UX2	A1S2UX3	A1S2UX4	A1S2UX5	A1S2UX6	A1S2UX7	A1S2UX8	A1S3UX1
1	1	3	1	5	1	1	1	1	1	1	5	3	4	1	0	0	4	3	4	3	5
2	4	1	1	1	0	0	1	4	3	3	4	2	4	3	0	0	5	4	3	3	5
3	5	1	1	2	0	0	0	5	3	3	5	3	5	4	0	0	4	4	4	4	5
4	5	3	3	5	0	0	0	5	3	4	5	4	5	5	0	0	5	5	4	3	5
5	3	3	1	3	0	0	0	2	2	2	3	2	4	2	0	0	4	4	4	3	4
6	2	1	1	2	1	1	1	3	3	3	5	5	1	3	0	0	2	2	5	3	1
7	4	3	1	2	0	0	0	3	3	2	5	4	3	2	0	0	3	4	5	2	3
8	4	4	1	1	0	0	0	5	4	4	5	5	5	4	0	0	5	4	3	5	3
9	4	3	4	4	0	0	1	3	4	3	5	5	4	5	0	0	5	4	4	4	5
10	2	1	1	4	0	0	0	1	1	5	5	2	3	5	0	0	3	4	3	4	3
11	5	1	1	4	0	0	0	4	2	4	5	2	4	3	0	0	3	2	3	4	5
12	4	4	3	2	1	0	0	3	4	3	4	4	3	1	0	0	1	1	5	3	3
13	3	4	1	3	0	0	1	3	3	2	4	2	5	3	0	0	5	2	4	3	5
14	3	1	1	1	0	0	0	2	1	1	4	4	3	1	0	0	1	1	3	2	1
15	5	2	2	1	0	1	0	4	2	1	3	3	5	1	0	1	4	2	3	4	4
16	5	4	3	2	0	0	0	5	4	2	5	5	5	2	0	0	5	3	5	4	5
17	4	1	1	3	0	0	0	4	1	4	4	3	1	5	1	0	1	5	4	3	1
18	1	2	2	4	0	0	1	1	2	2	5	1	5	2	0	0	5	2	4	3	5
19	5	2	2	3	0	0	0	5	2	3	5	5	5	3	0	0	5	3	5	4	5
20	5	2	1	2	0	0	0	5	2	2	5	5	5	3	0	0	5	3	4	5	4
21	4	1	1	1	0	0	0	4	1	1	4	3	3	1	0	1	3	1	5	4	3
22	1	3	3	2	0	0	0	1	2	2	5	5	5	2	0	0	5	2	4	5	4
23	2	1	1	5	1	0	0	2	1	5	5	5	5	4	0	0	5	5	5	3	5
24	4	4	3	2	0	0	0	4	4	2	5	5	4	4	0	0	4	3	4	5	2
25	3	5	2	3	0	0	0	3	3	3	5	4	5	2	0	0	5	3	4	4	1
26	4	1	1	4	0	1	0	5	1	4	5	5	5	5	0	0	5	5	5	4	5
27	5	1	1	1	0	1	1	5	1	1	5	5	4	1	0	1	4	1	5	5	5
28	5	1	1	5	0	0	0	5	1	5	5	5	5	5	0	0	5	5	5	5	5
29	4	1	1	3	1	0	0	4	1	3	5	5	5	1	1	0	5	5	3	5	3
30	1	3	4	2	1	1	1	1	3	1	3	5	1	4	0	0	1	2	3	5	1
31	5	3	1	3	1	1	1	5	3	3	5	4	4	3	0	0	4	3	3	3	3
32	5	2	1	4	1	0	0	4	2	4	5	3	5	4	0	0	4	3	5	4	5
33	5	5	1	5	0	0	0	5	5	5	5	5	5	5	0	0	5	5	4	4	4
34	5	1	1	1	0	1	1	4	1	1	5	3	3	3	1	0	2	2	3	4	2
35	4	1	1	1	1	0	0	2	1	1	4	1	4	2	0	0	2	1	2	1	1
36	4	1	1	2	0	1	0	4	3	3	4	4	4	2	1	0	4	2	4	3	4
37	5	1	1	1	0	0	0	5	3	3	4	5	5	2	0	0	4	2	3	5	4
38	1	2	1	1	0	0	1	1	3	4	4	2	4	1	0	0	3	1	3	2	5
39	3	1	1	5	0	0	0	5	1	1	5	3	5	5	0	0	4	4	5	4	5
40	4	1	1	2	1	0	0	4	2	2	3	4	3	3	0	0	3	3	2	3	2
41	4	4	4	1	0	0	1	4	2	1	5	1	5	1	0	0	3	1	5	2	1
42	4	1	1	2	0	0	0	4	2	2	4	4	4	4	0	0	4	3	4	4	4
43	4	1	1	1	0	0	0	4	1	4	3	3	5	1	0	0	5	1	2	3	4
44	5	2	4	1	0	1	1	5	1	2	5	4	4	2	0	0	4	3	5	4	4

Appendix Figure II. 9: Second phase studies - **Part B of the questionnaire data for P2-1 scenes (a)**

User session	A1S3UX2	A1S3UX3	A1S3UX4	A1S3UX5	A1S3UX6	A1S3UX7	A1S3UX8	A1S3UX9	A1S4UX1	A1S4UX2	A1S4UX3	A1S4UX4	A1S4UX5	A1S4UX6	A1S4UX7	A1S4UX8	A1S4UX9	A1S5UX1	A1S5UX2	A1S5UX3	A1S5UX4
1	1	1	0	0	4	4	4	4	3	1	5	0	0	3	5	2	5	3	3	1	1
2	1	1	0	0	4	1	5	3	1	1	4	0	0	1	4	2	4	3	3	1	2
3	1	1	0	0	5	4	3	5	1	1	5	0	0	1	5	4	4	4	4	4	5
4	4	3	0	0	5	4	5	5	4	4	5	0	0	4	5	3	5	5	5	5	5
5	2	1	0	0	4	4	4	4	2	1	4	0	0	4	4	2	4	4	1	1	4
6	1	1	1	0	2	2	5	4	1	1	2	1	0	2	2	5	4	1	3	1	3
7	2	1	0	0	4	2	5	4	2	1	4	0	0	2	4	3	4	2	3	2	3
8	4	1	0	0	4	5	5	5	5	2	5	0	0	4	5	4	5	5	4	1	5
9	4	3	0	0	5	3	5	5	2	3	5	0	0	3	4	4	5	4	4	3	4
10	4	4	0	1	3	2	4	2	1	2	3	0	0	2	3	4	3	3	4	3	4
11	2	1	0	0	3	2	5	4	2	1	4	0	0	3	3	4	4	5	3	3	4
12	2	2	0	0	4	3	4	4	1	2	1	0	0	2	2	4	4	1	3	1	3
13	3	2	0	0	5	2	4	3	3	1	1	0	0	2	1	5	5	5	3	1	3
14	1	1	0	0	1	1	4	3	1	1	1	0	0	1	1	4	1	1	2	1	1
15	2	1	0	0	5	2	5	4	4	1	2	0	0	3	2	5	3	3	3	3	2
16	3	1	0	0	5	3	5	5	2	2	5	0	0	2	4	3	5	5	5	3	4
17	1	1	1	0	1	3	4	4	1	1	4	0	0	1	4	4	4	5	1	1	1
18	3	1	0	0	5	1	5	4	1	1	3	0	0	1	1	5	4	2	3	3	2
19	2	1	0	0	5	2	5	5	2	1	5	0	0	2	5	5	4	4	4	3	4
20	2	1	0	0	4	2	5	5	1	1	3	0	0	1	3	5	4	5	4	1	2
21	1	1	1	1	3	1	4	4	1	1	2	1	1	1	1	5	3	5	4	2	4
22	3	3	0	0	4	4	4	5	3	2	4	0	1	3	4	4	5	5	3	3	1
23	1	1	0	0	5	1	5	5	1	1	3	0	0	1	3	4	5	1	4	4	5
24	4	2	0	0	2	4	5	4	5	3	4	0	0	4	3	5	5	1	5	2	4
25	3	1	0	0	1	3	5	4	3	1	2	1	1	3	3	5	4	1	5	1	5
26	1	1	0	0	4	1	5	5	4	3	5	1	1	3	4	2	5	5	1	1	5
27	1	1	0	1	4	1	5	5	1	1	1	1	1	1	1	5	4	5	3	3	4
28	1	1	0	0	4	1	5	5	1	1	5	0	0	1	5	5	5	5	5	3	5
29	4	1	0	0	4	4	5	5	1	1	3	0	1	1	3	5	5	1	5	1	3
30	4	3	0	0	2	4	4	5	3	3	4	0	0	3	4	2	5	2	2	1	4
31	3	3	1	0	4	3	3	4	3	4	3	1	1	3	3	2	2	5	3	1	4
32	1	1	0	0	4	1	5	2	1	1	4	0	0	1	4	5	4	5	3	2	4
33	5	1	0	0	5	5	5	5	5	1	5	0	0	5	5	5	5	5	4	2	5
34	1	1	1	0	2	1	2	2	2	1	1	0	0	2	2	5	2	4	4	1	4
35	2	2	1	1	1	1	5	1	2	2	1	1	1	1	1	4	2	4	3	1	3
36	2	1	0	0	4	2	3	3	1	1	1	0	1	1	1	2	4	4	4	2	3
37	2	1	0	0	3	2	3	4	2	2	3	0	0	2	2	4	4	4	4	4	4
38	3	1	0	0	4	3	5	4	1	1	2	0	0	1	3	2	3	5	4	1	3
39	2	1	0	0	3	4	5	3	4	4	5	0	0	1	1	4	4	5	5	4	5
40	2	1	1	0	2	2	5	3	2	4	3	0	1	2	3	4	4	1	1	1	3
41	3	2	1	0	1	2	4	1	3	1	1	0	0	3	1	4	2	1	1	1	1
42	1	1	1	0	4	1	3	4	1	1	3	0	1	1	2	4	4	1	1	3	4
43	1	1	0	0	5	1	5	3	1	1	5	0	0	1	5	5	3	1	1	1	1
44	1	5	0	1	3	1	5	2	3	5	4	0	0	1	4	5	2	1	2	5	3

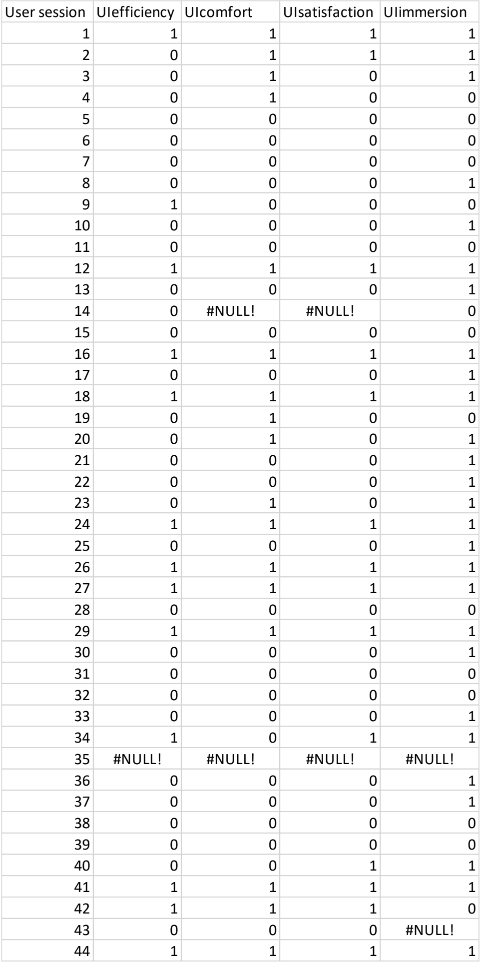
Appendix Figure II. 10: Second phase studies - Part B of the questionnaire data for P2-1 scenes (b)

User session	A1S5UX5	A1S5UX6	A1S5UX7	A1S5UX8	A1S5UX9	A1S5UX10	A1S5UX11	A1S5UX12	A1S6UX1	A1S6UX2	A1S6UX3	A1S6UX4	A1S6UX5	A1S6UX6	A1S6UX7	A1S6UX8	A1S7UX1	A1S7UX2	A1S7UX3	A1S7UX4	A1S7UX5
1	1	1	1	2	2	2	3	4	4	1	0	0	3	3	3	4	4	1	1	1	0
2	0	0	1	2	2	2	4	3	4	4	1	1	3	3	4	2	4	4	1	1	1
3	0	1	1	4	4	4	5	4	5	5	1	1	4	4	4	4	5	4	3	0	0
4	0	0	0	5	5	5	4	5	5	5	0	0	5	5	5	5	5	5	4	0	0
5	0	0	0	4	4	4	3	4	4	4	0	0	3	3	3	4	5	3	1	0	0
6	1	0	0	2	2	2	5	5	1	3	1	0	2	2	5	4	1	2	1	1	0
7	1	0	0	1	4	2	5	3	1	2	1	0	1	3	5	3	1	5	2	1	0
8	0	0	0	5	5	5	5	5	4	4	0	0	4	4	5	5	5	5	3	0	0
9	0	0	0	4	4	3	5	2	4	3	1	0	3	4	5	3	4	4	3	0	1
10	0	0	0	3	3	3	4	3	4	3	0	0	4	4	4	4	4	4	4	0	0
11	0	0	0	5	3	3	4	3	5	4	0	0	5	4	4	2	5	3	3	0	0
12	0	0	0	1	2	3	5	4	3	3	0	0	4	3	4	3	4	2	1	0	0
13	1	1	1	5	3	2	5	4	5	3	0	1	5	2	5	4	5	3	1	0	0
14	0	0	0	1	1	2	1	1	5	3	0	0	3	2	3	1	1	2	2	1	1
15	0	1	0	4	1	2	4	3	4	3	1	0	4	3	2	3	5	4	1	1	0
16	0	0	0	5	4	4	4	5	5	4	0	0	5	4	5	5	5	4	4	0	0
17	0	0	0	4	1	1	4	3	1	2	0	0	1	1	5	2	1	1	1	1	1
18	1	0	0	3	1	1	5	4	5	1	0	1	5	1	5	4	4	1	1	0	1
19	0	0	0	4	3	4	5	5	4	4	0	0	3	4	4	3	4	4	3	1	0
20	0	0	0	5	4	2	5	5	5	2	0	0	5	2	5	5	5	4	1	0	0
21	0	0	0	3	4	4	5	4	5	5	0	0	3	4	5	3	5	4	2	0	0
22	0	0	0	5	3	2	5	5	5	5	0	0	5	4	5	5	5	3	1	0	0
23	1	1	1	3	4	5	3	1	4	5	0	0	4	5	5	5	1	2	1	1	1
24	0	0	0	1	4	4	5	5	1	4	0	0	1	4	5	4	1	5	4	0	0
25	0	0	0	1	5	4	5	3	1	5	0	0	1	5	5	2	1	5	2	0	0
26	0	0	0	4	1	4	5	4	3	4	0	0	3	4	5	4	1	1	1	0	0
27	0	0	0	3	3	3	5	1	1	5	1	0	1	5	5	2	1	5	5	1	0
28	0	0	0	5	3	5	5	5	5	5	0	0	5	5	5	5	5	4	3	0	0
29	1	0	0	1	4	5	5	5	1	4	1	0	1	5	5	5	1	4	4	0	0
30	0	0	0	2	3	4	4	5	2	3	0	0	1	4	5	5	2	1	1	0	0
31	0	0	0	5	3	3	4	3	5	4	0	0	5	4	4	3	5	3	3	0	0
32	0	0	0	5	2	4	5	2	5	4	0	0	5	4	5	4	5	2	1	0	0
33	0	0	0	5	4	5	5	5	5	5	0	0	5	5	5	5	1	4	3	0	0
34	0	0	0	4	3	4	5	3	5	4	0	0	3	3	5	4	1	2	2	0	0
35	0	1	1	2	2	2	4	2	1	2	0	1	3	3	4	1	1	4	4	0	1
36	0	0	0	4	3	3	4	3	4	3	0	0	4	4	4	3	3	3	2	1	0
37	0	0	0	4	4	4	5	3	3	4	0	0	3	3	5	4	3	4	4	0	0
38	0	0	0	5	5	3	4	3	5	3	0	0	5	4	5	3	5	3	1	0	0
39	0	0	0	5	4	4	5	2	5	3	0	1	5	2	5	4	5	5	4	0	0
40	0	0	0	1	2	4	5	2	5	2	0	0	5	1	5	3	4	4	2	0	1
41	0	0	0	1	3	2	5	2	1	1	0	0	1	2	3	4	1	1	1	0	0
42	0	0	0	1	3	5	5	3	3	5	0	0	3	4	5	3	5	2	1	0	0
43	0	0	0	1	1	1	5	4	4	2	0	0	3	3	4	3	5	1	1	0	0
44	0	0	0	1	1	2	4	2	1	1	1	1	1	1	5	2	3	3	3	1	1

Appendix Figure II. 11: Second phase studies - Part B of the questionnaire data for P2-1 scenes (c)

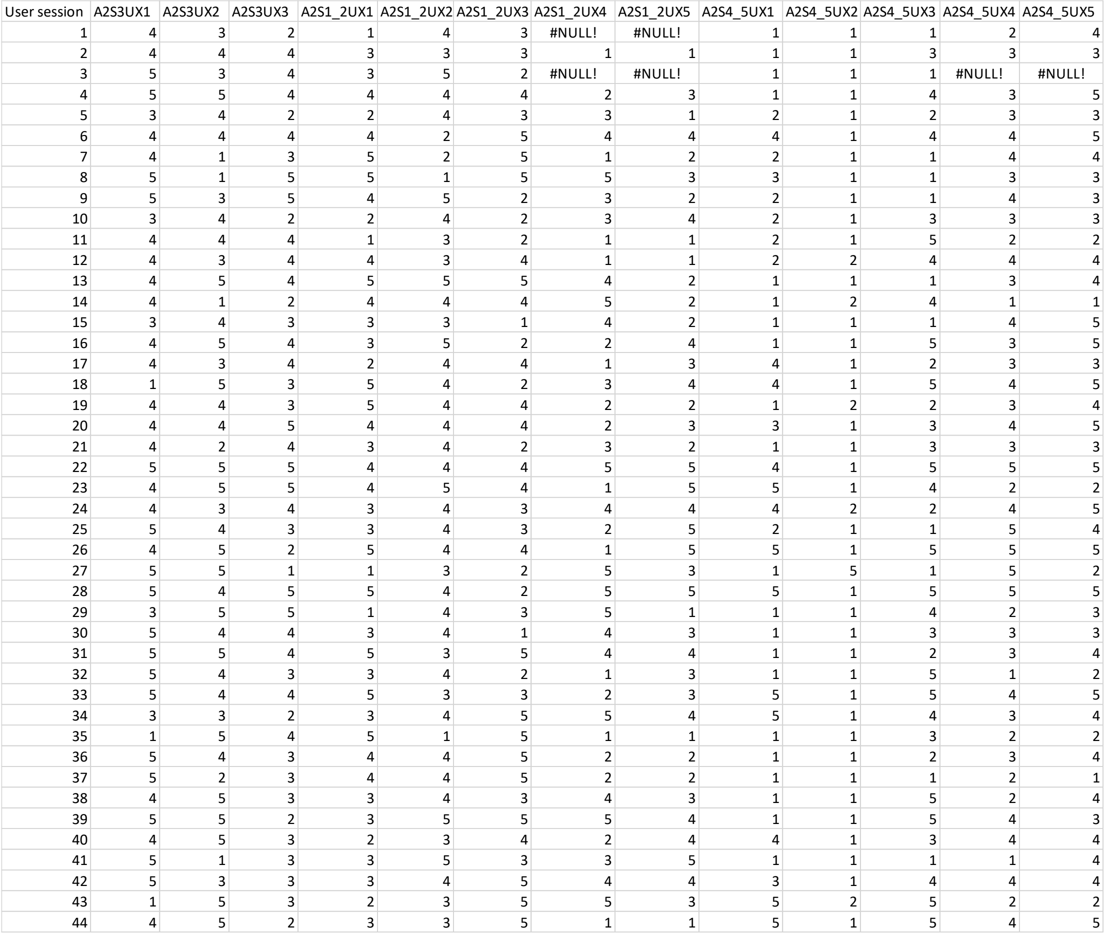
User session	A1S7UX6	A1S7UX7	A1S7UX8	A1S7UX9	A1S8UX1	A1S8UX2	A1S8UX3	A1S8UX4	A1S8UX5	A1S8UX6	A1S8UX7	A1S8UX8	A1S8UX9
1	3	3	4	4	4	3	5	0	0	4	4	1	5
2	4	4	4	3	4	3	4	0	0	4	4	2	4
3	4	4	4	4	4	3	5	0	0	5	5	5	5
4	5	5	5	5	5	4	5	0	0	5	5	3	5
5	3	3	3	4	3	3	4	0	0	5	5	2	5
6	3	3	5	4	3	1	3	0	0	3	3	4	5
7	1	5	4	3	5	1	5	0	0	5	4	4	4
8	5	5	5	5	5	3	5	0	0	5	5	5	5
9	4	2	5	4	4	4	4	0	0	4	4	4	5
10	3	3	4	4	4	4	1	0	0	3	1	2	3
11	4	3	4	3	4	3	4	0	0	3	3	4	3
12	3	2	5	4	3	2	3	0	0	3	3	4	4
13	5	4	5	5	3	1	2	0	0	3	2	4	5
14	2	2	3	1	3	3	2	1	0	2	2	3	1
15	4	2	4	3	4	2	4	0	0	4	4	3	3
16	5	4	3	5	4	5	5	1	0	2	4	2	2
17	1	1	4	3	1	1	1	0	0	1	1	4	3
18	3	1	5	4	2	1	1	1	0	1	1	4	4
19	3	4	4	4	4	3	2	0	0	4	3	4	5
20	5	4	5	5	4	3	4	0	0	3	4	5	5
21	4	3	5	3	4	2	5	0	0	3	4	5	3
22	5	3	4	5	4	3	5	0	0	3	4	4	5
23	1	1	5	1	1	1	5	0	0	1	5	5	2
24	1	3	5	3	3	4	5	0	0	3	4	4	5
25	1	5	5	2	4	2	2	0	0	4	4	3	3
26	1	1	5	3	1	1	5	0	0	1	4	2	3
27	1	1	5	1	1	5	5	0	0	1	5	5	2
28	5	4	5	5	5	4	1	0	0	4	1	5	5
29	1	1	5	5	3	4	1	0	0	4	1	3	4
30	2	3	5	5	1	1	3	1	0	1	5	5	5
31	5	3	2	4	4	4	1	0	0	4	1	2	3
32	5	1	5	2	4	3	4	0	0	3	4	5	3
33	1	4	5	5	4	4	3	0	0	3	5	4	5
34	1	1	5	3	4	3	5	0	0	3	4	5	2
35	1	2	2	2	4	5	3	1	1	3	3	3	3
36	2	3	4	3	4	3	2	0	0	3	2	3	4
37	2	4	4	2	4	5	3	0	0	4	3	4	3
38	4	4	5	3	4	2	4	0	0	4	3	4	3
39	5	4	5	3	4	4	3	0	1	4	1	5	3
40	3	2	5	5	1	1	2	0	0	1	3	4	4
41	1	1	4	4	1	1	1	0	0	1	1	5	3
42	5	2	5	4	4	3	4	0	0	4	4	4	4
43	5	1	5	3	1	1	5	0	0	1	5	3	4
44	2	1	5	3	4	5	4	1	1	1	2	4	2

Appendix Figure II. 12: Second phase studies - Part B of the questionnaire data for P2-1 scenes (d)



User session	UIefficiency	UIcomfort	UIsatisfaction	UIimmersion
1	1	1	1	1
2	0	1	1	1
3	0	1	0	1
4	0	1	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	1
9	1	0	0	0
10	0	0	0	1
11	0	0	0	0
12	1	1	1	1
13	0	0	0	1
14	0	#NULL!	#NULL!	0
15	0	0	0	0
16	1	1	1	1
17	0	0	0	1
18	1	1	1	1
19	0	1	0	0
20	0	1	0	1
21	0	0	0	1
22	0	0	0	1
23	0	1	0	1
24	1	1	1	1
25	0	0	0	1
26	1	1	1	1
27	1	1	1	1
28	0	0	0	0
29	1	1	1	1
30	0	0	0	1
31	0	0	0	0
32	0	0	0	0
33	0	0	0	1
34	1	0	1	1
35	#NULL!	#NULL!	#NULL!	#NULL!
36	0	0	0	1
37	0	0	0	1
38	0	0	0	0
39	0	0	0	0
40	0	0	1	1
41	1	1	1	1
42	1	1	1	0
43	0	0	0	#NULL!
44	1	1	1	1

Appendix Figure II. 13: Second phase studies – Data for Diegetic vs Non-diegetic UI evaluation



User session	A2S3UX1	A2S3UX2	A2S3UX3	A2S1_2UX1	A2S1_2UX2	A2S1_2UX3	A2S1_2UX4	A2S1_2UX5	A2S4_5UX1	A2S4_5UX2	A2S4_5UX3	A2S4_5UX4	A2S4_5UX5
1	4	3	2	1	4	3	#NULL!	#NULL!	1	1	1	2	4
2	4	4	4	3	3	3	1	1	1	1	3	3	3
3	5	3	4	3	5	2	#NULL!	#NULL!	1	1	1	#NULL!	#NULL!
4	5	5	4	4	4	4	2	3	1	1	4	3	5
5	3	4	2	2	4	3	3	1	2	1	2	3	3
6	4	4	4	4	2	5	4	4	4	1	4	4	5
7	4	1	3	5	2	5	1	2	2	1	1	4	4
8	5	1	5	5	1	5	5	3	3	1	1	3	3
9	5	3	5	4	5	2	3	2	2	1	1	4	3
10	3	4	2	2	4	2	3	4	2	1	3	3	3
11	4	4	4	1	3	2	1	1	2	1	5	2	2
12	4	3	4	4	3	4	1	1	2	2	4	4	4
13	4	5	4	5	5	5	4	2	1	1	1	3	4
14	4	1	2	4	4	4	5	2	1	2	4	1	1
15	3	4	3	3	3	1	4	2	1	1	1	4	5
16	4	5	4	3	5	2	2	4	1	1	5	3	5
17	4	3	4	2	4	4	1	3	4	1	2	3	3
18	1	5	3	5	4	2	3	4	4	1	5	4	5
19	4	4	3	5	4	4	2	2	1	2	2	3	4
20	4	4	5	4	4	4	2	3	3	1	3	4	5
21	4	2	4	3	4	2	3	2	1	1	3	3	3
22	5	5	5	4	4	4	5	5	4	1	5	5	5
23	4	5	5	4	5	4	1	5	5	1	4	2	2
24	4	3	4	3	4	3	4	4	4	2	2	4	5
25	5	4	3	3	4	3	2	5	2	1	1	5	4
26	4	5	2	5	4	4	1	5	5	1	5	5	5
27	5	5	1	1	3	2	5	3	1	5	1	5	2
28	5	4	5	5	4	2	5	5	5	1	5	5	5
29	3	5	5	1	4	3	5	1	1	1	4	2	3
30	5	4	4	3	4	1	4	3	1	1	3	3	3
31	5	5	4	5	3	5	4	4	1	1	2	3	4
32	5	4	3	3	4	2	1	3	1	1	5	1	2
33	5	4	4	5	3	3	2	3	5	1	5	4	5
34	3	3	2	3	4	5	5	4	5	1	4	3	4
35	1	5	4	5	1	5	1	1	1	1	3	2	2
36	5	4	3	4	4	5	2	2	1	1	2	3	4
37	5	2	3	4	4	5	2	2	1	1	1	2	1
38	4	5	3	3	4	3	4	3	1	1	5	2	4
39	5	5	2	3	5	5	5	4	1	1	5	4	3
40	4	5	3	2	3	4	2	4	4	1	3	4	4
41	5	1	3	3	5	3	3	5	1	1	1	1	4
42	5	3	3	3	4	5	4	4	3	1	4	4	4
43	1	5	3	2	3	5	5	3	5	2	5	2	2
44	4	5	2	3	3	5	1	1	5	1	5	4	5

Appendix Figure II. 14: Second phase studies - Part B of the questionnaire data for P2-2 scenes

User session	A1S1TimeLog	A1S2TimeLog	A1S3TimeLog	A1S4TimeLog	A1S5TimeLog	A1S6TimeLog	A1S7TimeLog	A1S8TimeLog	A2S3TimeLog	A2S4TimeLog	A2S5TimeLog
1	31,47714	19,33029	31,36639	23,41992	28,29980	37,10291	29,71094	60,01245	11,358220	8,521088	5,633545
2	21,29993	25,55533	18,28833	21,93341	16,14478	17,89954	23,76697	18,24438	9,071777	1,576172	3,111267
3	28,58823	21,63348	26,51160	19,13562	20,92242	29,08752	22,66650	29,74377	10,397890	1,676819	4,133240
4	27,72198	20,88910	28,17810	23,17883	20,73383	19,74213	24,36719	37,34503	18,708100	#NULL!	4,600159
5	21,81055	18,64545	20,82236	20,54224	20,20050	17,75427	19,28931	33,33411	12,977660	0,464630	2,822571
6	27,68832	17,98929	21,21118	17,29840	22,97772	17,98975	16,76550	28,13110	13,767520	#NULL!	3,677307
7	21,31102	17,60129	26,45563	21,29205	22,83295	13,88538	16,71130	21,69873	10,864320	6,743835	4,600037
8	20,18838	20,78893	22,23343	29,27734	25,03394	29,56653	29,94482	24,20813	21,588380	1,633301	3,222717
9	22,86638	56,58600	17,06696	27,01227	18,08899	16,29932	22,82227	20,78992	18,680420	12,320560	1,733582
10	22,98849	34,91153	24,81143	21,59906	19,91119	16,87769	23,61151	22,23364	15,610990	13,794130	1,366989
11	28,13293	38,64513	19,37793	22,77844	23,60040	17,70081	19,77789	20,71149	11,431210	4,744446	3,256317
12	23,54451	15,89838	18,34451	13,63190	14,15558	12,46277	13,56598	13,77551	19,524840	2,987549	#NULL!
13	22,76622	16,51108	15,18912	17,58087	16,80029	15,27533	15,24438	14,32104	12,966800	3,577240	8,278076
14	18,55585	27,23050	20,84464	24,40130	28,42273	14,56433	14,86700	17,95428	13,264890	0,975708	#NULL!
15	26,75580	17,01129	21,97800	19,49584	16,26636	22,02234	19,94464	19,48761	9,267212	1,642578	2,877472
16	37,54456	29,72290	37,45566	42,10128	33,27844	28,58765	60,01111	47,68835	13,687260	#NULL!	#NULL!
17	17,58905	23,37567	20,80023	21,15363	13,50031	11,05383	10,76721	12,34088	11,531490	3,743958	2,388611
18	19,15524	22,83191	16,81079	17,38672	15,04431	13,55652	18,73376	14,85486	13,589360	#NULL!	5,455811
19	17,68857	13,54483	18,41142	17,71231	16,84467	13,87439	15,44482	16,84229	6,716919	0,865875	#NULL!
20	20,90057	26,15598	27,56691	30,68510	19,34497	17,13391	20,66730	23,04523	6,608826	8,731598	5,889374
21	14,18866	12,97827	16,73346	15,52301	11,44443	11,24323	11,41089	20,49543	9,857483	2,287338	2,411072
22	14,76685	16,67786	16,89954	15,94629	12,06647	18,98624	13,41061	18,88910	32,119630	3,521423	2,289063
23	43,73340	25,41064	38,47791	45,85730	60,01160	32,07587	19,44431	26,78966	25,633480	2,842255	3,399933
24	20,47754	28,78772	17,76660	27,64685	25,18909	22,58582	16,03381	23,16755	12,188110	7,410126	10,711610
25	20,12256	26,75671	21,67773	21,23230	17,53351	16,70007	21,63330	51,18781	9,400330	4,900024	6,966858
26	25,15576	17,71228	23,57855	47,16669	20,39969	19,75955	16,67751	30,49023	11,965820	21,910130	6,756012
27	27,30017	16,41064	19,47778	21,38818	19,73297	18,09097	18,24463	20,65778	6,313477	2,466187	6,766785
28	34,10022	21,62213	19,15558	27,56610	28,23337	16,05438	17,26695	23,33491	16,314030	#NULL!	4,822815
29	31,27795	47,12329	21,12244	24,69861	25,71130	26,91339	22,95572	60,01205	51,401250	1,631836	2,667023
30	60,01184	74,44629	32,26685	57,74847	27,84521	23,61426	38,22302	42,20911	10,724790	0,772430	3,477844
31	24,22238	20,77182	22,22189	29,97785	20,02222	16,67780	18,81140	26,60039	8,844238	4,088135	8,322327
32	19,58984	24,23267	17,69995	22,59991	13,58896	24,39993	14,67746	20,65003	13,389620	1,899658	1,822662
33	25,77856	54,36646	26,22223	30,92395	19,74438	16,91132	32,91135	60,01180	14,901060	9,486755	3,977753
34	15,51135	18,61292	20,76642	18,66705	19,74481	10,45755	16,74490	18,23284	9,967346	#NULL!	#NULL!
35	25,88940	20,06900	18,76736	27,15598	22,78918	13,11176	29,63358	44,57747	45,866060	1,964417	5,122589
36	17,15588	15,51050	12,61157	14,97809	14,31165	14,17752	16,55568	28,87975	7,575653	#NULL!	1,644318
37	19,40015	17,63428	16,98889	20,44751	12,73376	34,92267	20,50018	14,72205	10,119200	#NULL!	0,522614
38	37,79883	51,33420	21,83350	30,51270	25,52258	20,44629	17,35510	27,26355	17,433530	#NULL!	5,077972
39	50,01111	40,40862	22,27730	26,76782	17,10022	19,59900	28,70013	17,50232	6,268005	2,965759	#NULL!
40	33,63327	23,50815	32,28857	33,64453	29,39977	25,21112	27,72266	23,38971	9,418457	4,629761	4,944641
41	19,06726	11,63196	18,46680	16,88794	20,99954	39,23083	41,28915	41,83264	15,697690	2,676758	4,689209
42	17,94470	16,42432	22,86676	21,51044	17,44413	13,13382	18,63281	17,92169	28,499050	6,987724	#NULL!
43	24,04468	24,38129	17,52246	19,15326	24,83270	22,93558	15,77765	27,46732	11,531800	1,220367	5,656403
44	35,28882	20,43201	26,41138	24,03088	26,00008	28,41002	28,21167	25,98981	8,377136	#NULL!	2,144653

Appendix Figure II. 15: Second phase studies – Log data reconrding time in seconds for P2-1 scenes

Appendix III– Ethics consideration

In order to proceed with testing the prototype with users to collect data related to user experience, the study had to comply with the University ethics guide (University of Westminster Code Of Practice Governing the Ethical Conduct of Research 2017/18 | The British Educational Research Association document Ethical Guidelines for Educational Research 2011). University ethics approval has been acquired for this study and a consent form has been prepared and signed by all the participants along with a participant's information sheet giving them information about the purpose of the study. Therefore, in order to conduct the research study, the following ethical issues had been addressed:

- informed consent is granted from participants and that these are treated with dignity and without prejudice;
- there should not be coercion in recruiting participants;
- confidentiality and anonymity of participants personal data in accordance with the Data Protection Act (1998);
- the researcher has a responsibility to design a study that is inclusive, fit for purpose and produces meaningful data.