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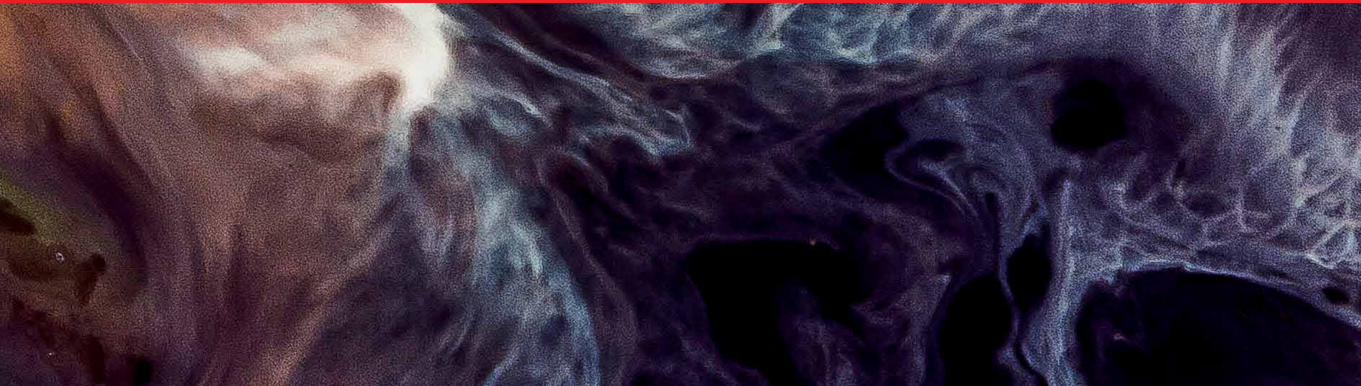
Virtual Reality and Its Application in Education

Edited by Dragan Cvetković



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Published in London, United Kingdom







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http://dx.doi.org/10.5772/intechopen.80114
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First published in London, United Kingdom, 2021 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, 5 Princes Gate Court, London, SW7 2QJ, United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Virtual Reality and Its Application in Education
Edited by Dragan Cvetković
p. cm.
Print ISBN 978-1-83880-860-0
Online ISBN 978-1-83880-861-7
eBook (PDF) ISBN 978-1-83880-862-4

Meet the editor

Dragan Cvetković graduated in Aeronautics from the Faculty of Mechanical Engineering, University of Belgrade, in 1988. He defended his doctoral dissertation in December 1997. He has published 64 books, scripts and practicums about computers and computer programs, aviation weapons and flight mechanics. He has also published a large number of scientific papers, both nationally and internationally. In 2014, he became a full professor in the field of Informatics and Computing at Singidunum University, Belgrade. Previously he had served as an assistant professor. He has been Vice Rector for Teaching at the same university since 2019.

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Preface

Every time some new media appear, civilization accelerates in different directions. Earlier, time "passed" more slowly and was measured in weeks, days, hours and minutes. Nowadays it is measured in seconds, and the time will surely come when it will be measured in milliseconds. It is obvious that everything is accelerating with the appearance of new technology. We are currently living in the era of high-speed internet, laptops, smartphones and watches, but we are approaching the moment when we will live in the time of a new medium - virtual reality.

The constant development of computers and information technologies enables the realization and application of new methods and systems that were not possible before. One example of such a development is virtual reality (VR), also known as "virtual environment." With the techniques and technologies of VR, it is possible to realize realistic simulations that are useful in various areas of human activity. Simulations have been known before, but VR techniques and technologies can give the impression of a person entering a non-existent or apparent world.

What is VR? It is a set of technologies that enables two-way communication, from computer to user and vice versa. In one direction, technologies are used to synthesize visual, auditory, tactile and sometimes other sensory experiences in order to provide the illusion that practically non-existent things can be seen, heard, touched or otherwise felt, which are defined and placed in computer memory. In the other direction, technologies are used to adequately record human movements, sounds or other potential input data that computers could process and use. This human-computer interaction is used to "create" an interactive interface between virtual worlds and people or other types of users. If more than one user participates in this process, then VR can also be understood as a medium.

It is certain that the human race will have to change habits and accept new rules regarding business, education, sales and advertising, among others. The mentioned rules imply the use of new technologies that are already here. VR has found application in the film and entertainment industry (primarily in computer games), architecture, mechanical engineering, medicine, the military, education, sports and many other fields. It is evident that VR represents a new future for the human race.

The introductory chapter presents the definitions and principles of VR, potential applications of VR and Augmented Reality (AR), and describes devices for VR. Chapter 2 clarifies the relationship between the body and the tangible or visible form of an idea, quality or feeling, in AR and VR, and the implications of essentialism, for the virtual sublime. Chapter 3 synthesizes recent studies into a set of educational design principles for effective use of VR, discusses practical implications and provides a future research agenda for the higher education context. Chapter 4 deals with technology education, its expectations and its present state, especially in developing countries. It emphasizes its development, types and uses and how it can be applied to improve teaching and learning. Chapter 5 presents the potential usage of VR devices for informal education in technical and natural sciences.

Chapter 6 presents a specific methodology for building an interactive and immersive VR installation for people with disabilities.

I would like to express my sincere gratitude to all the authors and co-authors for their contributions. The successful completion of this book has been the result of the cooperation of many people. I would especially like to thank Publishing Process Manager Ms. Marijana Francetić for her support during the publishing process.

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Chapter 1

Introductory Chapter: Virtual Reality

Dragan Cvetković

1. Introduction

The constant development of computer and information technology allows the implementation and application of new methods and systems that were previously not possible. One example of such a development is the technology of virtual reality (VR) or virtual environment (VE). With virtual reality techniques, it is possible to achieve realistic simulations that are useful in many areas of human activity. Simulations were known even before, but virtual reality techniques can provide the impression of "stepping in" the apparent world [1, 2].

This impression of presence in the apparent world is possible by using advanced computer and communication devices between a man and a computer. Virtual reality techniques also use modern computer networks to achieve communication between a man and a remote environment with the aim of achieving functioning at a distance.

At the beginning of the twentieth century, public perception of virtual reality was quite distorted. In fact, thanks to its presence in the media, virtual reality was expected to be a miracle. But, despite some predictions, virtual reality did not come into extensive use. Thus, a part of the public and some experts changed their minds significantly and declared that technology is useless [1, 3].

2. Definition and principles of virtual reality

To make the concept and principle of virtual reality clear, at the very beginning it is necessary to clarify the concept of perception. Perception is the process in which man collects and interprets information about the world around oneself. Senses and the brain participate in the process of perception.

There are two kinds of senses—external and internal. External detect phenomena outside the body, and the inner detect the phenomena within the organism (hunger, fatigue, pain, thirst, etc.). The external senses can be divided into remote (heat, eyesight, hearing) and contact (smell, touch, taste). When it comes to virtual reality, only systems that affect the remote senses are well developed, though systems that affect the contact senses will gradually evolve in the future.

Senses transfer information from the environment, while the brain interprets received information. Beside the senses, the perception is also influenced by experience, knowledge, emotion, and motivation. In order "to cheat" the system of perception, the basic idea is that the real stimuli received by the senses should be replaced by artificially generated stimuli. In this way, the real environment can be replaced by apparent environment. As a result, it appears that the system of perception creates the impression of the presence of people in the apparent, nonexistent environment.

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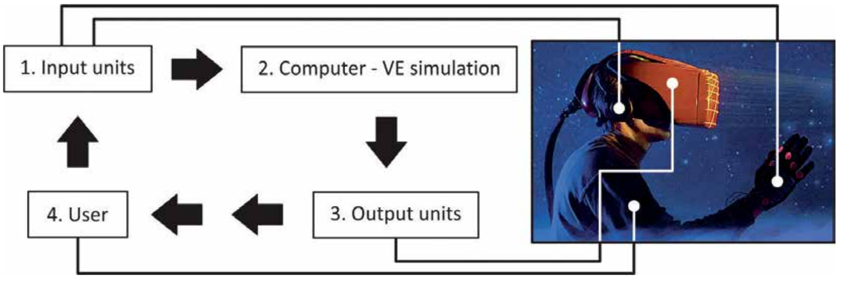

Figure 1.
The principle of virtual reality.

Virtual reality is a computer-created sensory experience that allows the user to believe in the apparent reality. The user is then either completely surrounded by these virtual world or partially included by listening and watching virtual reality applications. Virtual reality is a collection of technologies that "inserts" users in a virtual environment. Ideally the user's senses detect only virtual stimuli produced by a computer, and user's movements are directly entered in the computer.

Virtual environments are based on objects defined in the computer's memory in such a way that a computer can later be attached to these items on the screen with the possibility of interaction. By combining the elements of the unreal (imaginary) environment and the real environment (which can also be remoted), the user creates a feeling of presence in a virtual environment. This is illustrated in **Figure 1**.

The following figure shows the basic principle of virtual reality. The user is in a closed loop and one is connected to a computer with input and output units. Input devices (1) follow the movements of the user and pass them to the computer (2), which makes the simulation of a VE to be based on these and other data. With the help of output units (3) the computer shows a virtual environment, as real as it is possible. Ideally, the user's senses should only detect artificially generated stimuli (from the computer), and thus the real would be completely turned off. In the example shown in **Figure 1**, the user (4) sees only the image generated by the computer. Thereby, the loop is closed, and the user directly sees and hears (and possibly feels, smells, tastes, etc.) virtual environment with the immediate results of his own movements.

3. Virtual reality equipment

Firstly, virtual reality devices can be divided into input and output. Secondly, previously mentioned devices can be further divided into types and subtypes within each category. The input devices include the following:

- **Position/orientation sensors**—electromagnetic, acoustic, optical, mechanical, and inertial

- **Force/momentum sensors**—*Spaceball*, etc.

- **Body/arm position sensors**—sensor glove (*data glove*) and sensor suit (*bodysuit*)

- **Motion sensors**—treadmill, bike ergometer, rowing ergometer, etc.

- **Other sensors**—control through breathing, face tracking, eye tracking, and voice recognition [1, 4]

Electromagnetic sensors use a source of electromagnetic field, and the position of source is fixed and previously known. Sensors located on the head and hands of the user receive an electromagnetic signal and transmit it to a central unit. That unit based on the received signal counts the position and orientation of sensors within the electromagnetic field (the position and orientation in relation to the source) [1, 5].

Acoustic sensors work in a similar way as electromagnetic. The only difference is that instead of electromagnetic waves, each transmitter sends high-frequency sound to the receiver—special microphone. Advantages of this system are good and acceptable price range, but this system has its drawbacks as well. Between the transmitter and the receiver, there must not be any obstacles, the system cannot support a larger number of simultaneous sensors, their accuracy is worse than the accuracy of magnetic sensors, and the dimensions of the receiver may represent difficulty for particular applications [6].

Optical sensors (*motion tracking*, *optical motion capture*) are part of a system which follows signs (markers) with numerous cameras, thus calculating the position of markers in space by combining positions of markers in field of vision of each camera. These systems use different principles of monitoring, usually with the help of markers of lustrous material. Cameras, sensitive to infrared light, monitor markers or body movements in space. The cameras must be calibrated, i.e., their relative position and orientation must be known. By combining 2D track position of markers (from all the cameras), with information about the location and characteristics of each camera, 3D position of markers can be precisely determined. The main advantages of the optical monitoring are extremely high accuracy, a large amount of sampling data, and the possibility of simultaneous use of a large number of sensors [4, 6].

Mechanical sensors are conceptually simple. There is a mechanical structure with a number of joints that measures the angle of rotation of the joint. From these angles, known length of the segments between the joints, simple solving of direct kinematics one can obtain the position of the posterior segment compared to the first (fixed) segment of the structure. The so-called exoskeleton (mechanical structure installed on the body, **Figure 2**) can use mechanical tracking for the monitoring of joints position in the body and thus the position of the entire body. The advantages of such devices are high precision and high sampling rate, but the size is a reason for impractical production [1].

Figure 2.
Exoskeleton: mechanical construction installed on the body.

Inertial sensors measure acceleration and angular acceleration of each segment, thus defining their position and orientation. Because of measurement accuracy, it is highly necessary to determine the starting position precisely.

Force sensors (momentum sensors) are devices that measure the force, or momentum, and they can be a part of devices such as Spaceball or a part of more complex system for simulation of force or touch. They are also used for more intuitive manipulation of 3D objects and more natural motion through the virtual environment.

Body position sensors are composed of a large number of sensors for registering the position and orientation that are integrated into the suit. The information, which are emitted by sensors almost completely in real time, describe the movement of the segments in space.

Arms position sensors (*data glove*) are the input devices in the form of a glove. There are a number of sensors that register the position of the hand and fingers by measuring the angle displacement. This type of device can be combined with the simulators of force or touch glove, thus becoming a haptic output device.

The role of the **motion sensors** consists of marking the position of objects in the real world and forwarding the information to the computer. Processed information about the position of the body computer saves, graphically displays, or assigns to the object which is in the interaction with the user.

A common feature of previously mentioned systems is the ability to collect information (*motion capture*) about the position of referent points in space in real time. The data can be used to visualize situations in three dimensions and their analysis. Different applications for 3D modeling and animation are able to use information gathered from sensors [1, 4–6].

The **output devices** include:

- **Devices for 3D display**—stereo glasses, *head-mounted display*, stereo screens (with interchanging images or double vision), and projection systems (stereo projection on a screen, cave automatic virtual environment (**CAVE**), wide-angle projection, virtual worktable)

- Devices for 3D sound synthesis

- **Devices for synthesis of sense of touch and force**—tactile output devices, devices for force feedback, and the mobile platform

- **Other devices**—odor, wind, and heat

In order to achieve the stereoscopic effect, it is necessary to project two images, one to each eye at a time. *Head-mounted display* (**HMD**) has a separate screen for each eye (**Figure 3**). Due to the small dimensions of the device, the screens are

Figure 3.
Head-mounted display.

too close to be directly observed, so it is necessary to set the corresponding optical system that allows the user to view the screen, between the eye and the screen itself [4].

The most important characteristics of **HMD**, apart from the size, weight, and comfort, reflect in the range of view angle and screen resolution. They can be found in various forms, from the helmet to the goggles. Today, there is a tendency toward minimalist approach and practical applicability. The aim is to create a device that is small enough not to interfere free movements. Such devices can be equipped with headphones and position and orientation sensors.

The most advanced **projection system** is **CAVE** system. It consists of the area bounded by the projection screen (which creates the room where the user is located) on which are projected computer generated stereo images. The user wears glasses which guarantee a three-dimensional experience, thus providing the satisfactory peripheral vision. The experience is very realistic so that connections between the set of projection canvases is almost invisible.

Sound simulation includes the reproduction or generation of a sound in a virtual environment. By including a three-dimensional sound, we can get an idea of precise location of the sound source in space. The effect can be achieved by the difference in received sound volume in the left and the right ear, by the reflection of sound waves in the ear lobe and its surrounding, and by combining the results of this reflection for different frequencies, which are an integral part of the sound.

Haptic devices allow the simulation of touch and/or force that can cause the sensation of contact (touch) with the virtual object. **Simulation of touch** (*tactile feedback*) is usually based on thermal or vibrating elements which the user wears on his fingers and that are activated when the user “touches a virtual object.” For this operation, one has to track accurately the location of user, more precisely his hands. **Simulation of force** (*force feedback*) includes the monitoring of the position with the inclusion of active elements (motors, electromagnets, servo motors) that exert force on a user’s hand, other parts of the body, or a tool one handles.

Moving platforms are haptic systems that simulate the position of the user by moving the entire platform on which the user stands or sits. Compliance of the position with the visual information increases the feeling of participation in the simulation. This type of haptic systems is commonly used in complex simulators, car or plane driving simulators, etc. [4–6].

4. Applications of virtual reality

Virtual reality is mostly applied in the following areas: medicine, military industry, education, entertainment, design, and marketing.

Medicine is the field where the virtual reality had an enormous success and it is still expanding. It is used in the field of surgery, both for training (learning on virtual human models) and for planning of a surgery. 3D displays can be obtained from medical images, as it is the case in modern medical devices. In psychiatry, the virtual reality is used to treat a variety of mental disorders, starting from fear of flying to posttraumatic stress disorder [1, 6].

One of the biggest investors in the field of virtual reality is military organization, and many VR technologies are embedded in various military equipment simulators. Simulations of various vehicles are among the most common applications of virtual reality. Many experts are trained in different simulators, and it is particularly important that the situations which in reality rarely occur (e.g., rescue of hostages) can be trained.

Virtual reality can also be used for the presentation of future projects in architecture, for creation of future product prototypes, etc. It can be also used as a successful tool for the promotion and marketing at exhibitions and fairs because of the fact that 3D projection is still interesting enough to attract the curious [1, 7].

Virtual reality is ideal for the entertainment industry, because of its possibility to create an illusion. More and more games that use this technique are turning up in gaming lounges, and it is a question of time when this technology will be available to everyone who wants to use it, even at home.

Despite the numerous areas of application, there are also some limitations. Although in recent years, there has been a considerable progress, the equipment is still impractical, huge, expensive, and complex. Certain types of virtual reality can cause nausea, and even if they do not cause certain health issues, they are too uncomfortable for long-term use [7, 8].

5. Augmented reality

Augmented reality (**AR**) adds the elements of virtual environment to the real world so they could look like the part of it. This user's view of the world expands with additional information that are directly embedded into the real world. In some applications, it is not necessary to replace reality with the virtual world, sometimes it is only requisite to complement or enhance it with some parts of virtual reality [9].

Augmented reality is a relatively new area. Although the basic idea appeared in the beginning of twentieth century, its rapid development has started at the end of the same century. That is the reason why this technology has not still achieved its full expansion. It provides direct access to the information so that they are displayed in the user's field of vision and intertwined with the real world. This allows faster, better, and easier access to information [8–10]. It can be applied in the following areas: medicine, manufacturing and maintenance, architecture, robotics, military industry, and entertainment. When it comes to medical application, medical images are overlaid with the patient, resulting in a kind of virtual X-rays but in real time. The resulting effect is reflected in the fact that the doctor can see the patient's organs as the body is transparent [8, 9]. For now, they are not widely used. In the production and maintenance, visual instructions are displayed directly on the equipment/machinery, and the operator, instead of looking the documentation, has all the necessary information at the right time in the right place. Augmented reality can be used in interior design, visualization of structures, or installations. For example, virtual furniture can be deployed in the actual room; thus one can get an impression of spatial relations and how the rooms will really look like with some furniture. With the help of augmented reality, military pilots can receive additional information, such as guidance, see the targets or guided missiles. The display is built into the helmet or in the cabin [8].

Augmented reality has a great potential, but today's systems of augmented reality are still quite cumbersome and imprecise and consume too much energy, so it is necessary to solve these problems.

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Chapter 2

Sensuality, AR/VR, and the Virtual Sublime

Lynne Heller

Abstract

This article investigates the body, embodiment, augmented, virtual reality (AR/VR) and the virtual sublime. Through AR/VR one negotiates virtual worlds, often with a feeling of endless possibility and sublimity. This experience can lead to the danger of being swallowed up by the sublime. However, instead of being confronted by nature and the immensity of the skies, the virtual sublime references technology, infinitely zooming into microscopic and atomic structures, yet still shaking our sense of our world. The concepts of virtuality, digital materiality, the analogue/digital divide, an AR/VR spectrum, essentialism, sensorial sensuality and avatar instantiation will be explored, concluding with an analysis of the senses and the natural extension of sensorial engagement—affect. This article proposes that the heightened sensations of an AR/VR encounter lend themselves to the sublime. However, the deficit of AR/VR sensuality due to truncated sensorial input leads to feelings of disaffection and disconnection. The residual effect translates into a longing for a heightened engagement and becomes a yearning for the sensual input of physicality. Yearning therefore becomes a defining attribute of the virtual sublime. These ideas are considered in light of the philosopher Henri Bergson's concepts of the absolute and the relative.

Keywords: sensorial sensuality, AR/VR, virtual sublime, immersion, embodiment

1. Introduction

This text explores the body in augmented and virtual reality (AR/VR) and the implications of essentialism for the virtual sublime. The concepts of virtuality, digital materiality, the analogue/digital divide, an AR/VR spectrum, essentialism, sensorial sensuality, and avatar instantiation will be explored and conjoined, concluding with an analysis of the desire for experiences of the senses and the natural extension of sensorial engagement—effect. I propose that the heightened emotion and physical sensations of an AR/VR encounter lend themselves to an alignment with the sublime. However, the deficit of AR/VR sensuality due to truncated sensorial input leads to feelings of disaffection and disconnection. The residual effect of this less than optimal embodiment translates into a longing for a heightened engagement and becomes a yearning. Yearning then becomes a defining attribute of the virtual sublime. These ideas are considered in the light of the philosopher Henri Bergson's concepts of the absolute and the relative.

I have spent considerable time, both motivated and frustrated, in virtual worlds. Most of the time I have been a creator in AR/VR spaces, which perhaps leads to more excessive reactions to the medium as I seek to impose my artistic will through an inherently collaborative process. I only have the affordances and range for self-expression that the application's coders and designers think to offer, accidentally program or intentionally impede. Contemplating this often one-way street of *collaboration* during both the highs and lows of making led me to think deeply about my experiences in AR/VR. Why was it such an exciting and propulsive activity, along with being a source of deep disappointment? I will approach this writing primarily as a maker but draw on other artists, designers, writers, and theorists to help me understand why I am continually drawn back to thinking about and working with AR/VR.

Composing this introduction in the time of an international pandemic is particularly instructive. It is impossible to ignore the terror and disruption a virus has created the world over. Sadly, little of the fear most of us are feeling could be typified as sublime. The sublime, along with its dose of danger, has a positive connotation of transcendence and awe [1]. However, how to look after ourselves physically and psychologically has suddenly come to the fore in most people's everyday existence. We can never escape our bodies as much as Eurocentric philosophical thought and academic traditions have sought to divide the intellect from our material existence. So one comes to terms with the body, a truce of sorts, particularly as one is made aware of an imminent danger to it. However, it is difficult to shake the mindset that there is a way to *outthink* our physicality and soar to great heights if only we didn't have to deal with flesh, blood, and bones. This is the promise of virtual existence and its Achilles heel. Virtual interaction has, seemingly overnight, become a mainstay for people with access to internet speed and applications such as FaceTime, Zoom, WhatsApp, and Microsoft Teams. With this acceleration into the virtual futurity, questions of sensuality, effect, and emotional engagement are timelier than ever [2, 3].

2. Virtuality

Virtual is a word tossed around on a daily basis now, a punchline for the gallows humour we engage in as we congregate around our internet water coolers. It has become a catchall word for communication and interpersonal relationships at a distance. As we are so reliant on digital technology for communication at a distance, common parlance often conflates the digital and the virtual. In this text, the digital is critical to enacting the virtual. However, they are different. To be blunt, the digital is the conversion of information into binary numbers—the virtual is our imagination.

Virtuality is a philosophically knotty discussion. The concept is considered extensively in the writings of thinkers such as Henri Bergson [4], Gilles Deleuze [5], Elizabeth Grosz [6], Pierre Lévy [7], and Brian Massumi [8], to name a few. It could even be said to be fundamental to the discussion of idealism versus realism or materialism, around which so much philosophical discussion is centred. However, three specific notions define the idea of virtuality in current digital culture, making them particularly pertinent to this text. One; the capability of "functioning or being used as, but not constituting, the physical object or entity represented. For example, virtual memory is memory that a microprocessor can use, but it doesn't correspond to actual chips in RAM." Two; existence "in the form of, or by making use of, digital media. For example, groups of people who do not live near each other but who share a common interest or concern and keep in contact by means of the web can be said to be a virtual community." Three; something that relates to or is existing in virtual reality [9].[1]

[1] Another definition of virtual, and my personal favourite, comes by way of the *New Oxford American Dictionary*, though very poetic is unintelligible to me. They define the word as an adjective and suggest that it is "Optics relating to the points at which rays would meet if produced backward" [10]. This is somewhat mysterious but a completely delightful sentence begs the question—What exactly would rays meeting, produced backwards, look like?.

Virtual reality, on the other hand, is an ambiguous term "referring loosely to a broad spectrum of new media technologies which enable the user to interact with computer-mediated representations or simulations, and by implication also to any experience generated or mediated by such means" [11]. For example, video conferencing or video games could be considered virtual reality. It can also refer to "cutting-edge sensory immersive technologies which use head-mounted displays and an elaborate array of body sensors in order to enhance, elaborate, and expand our sensory interaction with new media objects" [11]. The term is oxymoronic—what is the virtual has generally not been equated with the *real*. From a "metaphysical perspective, virtual reality might complicate various issues pertaining to the age-old distinction between appearance and reality, since a new media object in a virtual reality environment may be a representation of something real, that is, a copy, and a genuine unique object at the same time" [11]. Following on virtual environments are "simulated computational" models designed to interact with people. "They can have objects representing real or abstract entities that have a simulated physical representation" through digital materiality, tools, and technology, principally using AR/VR devices and apps [12].

3. Digital materiality

The digital is implicit in the virtual which is popularly experienced through AR/VR technology. Less obviously, the virtual is imperative to the digital in that one needs to imagine what is possible through digital materiality. Along with digital tools, processes and networks comes a materiality that starts with electricity, more particularly the state of the electricity, registering as on or off, and then converted to corresponding zeros and ones. The zeros and ones are, in turn, built into low-level languages that allow for sophisticated programs which can then control the ensuing digitized output. The electricity and recorded states are ephemeral but they are still material, even if that materiality eludes our human, immediate, senses. It is hoped we do not experience a jolt of electricity directly, but rather, see the results of it and therefore know it exists. Digitized output is how this materiality is commonly experienced. The light waves transmitted through screens hitting our eyes and sounds through speakers hitting our eardrums are elusive but material. The digital has these concrete manifestations even if it is made of and from substances such as light, sound, waves, and wattage, substances not often described as material. But they are. Electrons and sound waves are physical phenomena.

The relationship between the digital and virtual is not just substance versus concept. The virtual we experience is a unique product of the digital means enacting it. All materiality and process suggest more than just what meets the eye/ear/nose. When we look at or experience an object, we see and intuit the combined histories of the substances and processes that went into its creation. That is also true when experiencing virtually. Brian Massumi in *Parables for the Virtual* insists that:

> *The digital is a numerically based form of codification (zeros and ones). As such, it is a close cousin to quantification. Digitization is a numeric way of arraying alternative states so that they can be sequenced into a set of alternative outlines. Step after ploddingly programmed step. Machinic habit…The medium of the digital is possibility, not virtuality, [original emphasis] and not even potential. It doesn't bother approximating potential, as does probability. Digital coding per se is possibilistic to the limit.…Nothing is more destructive for the thinking or imaging of the virtual than equating it with the digital [8].*

To some extent, Massumi is correct in thinking that the digital and virtual can not be equated; however, they are productive for each other. Massumi's thinking conflates a constraint of means, the 'possibilistic' nature of the digital with what people can do within and with constraints. This is similar to arguing that anything made with paper and pen is limited because of how paper and pens are manufactured. In art making, the issue is not only the materials at hand, though contra Massumi, constraints of materiality often contain the gift of serendipitous intent or meaning; but rather possibility inherent through the intention of the artist, manipulation of audience reception, wish fulfillment, and force of inner vision conveyed, no matter whether the artist is using analogue or digital technology. As well, the assumption that possibility is only 'plodding' is near-sighted. Exploring/exploiting even the simplest of digitally calculated possibilities could take a lifetime, making this abstract notion of possibility infinite. That computers can do the plodding for us and give us an infinite array of possibility, seems like a creative positive rather than the negative Massumi seems to attribute to it. This is surprising given his obvious admiration for artistic methodology elsewhere in his writing [8]. Henri Bergson refutes the idea that quantification is limited by proposing that "…though mathematical processes are applicable only to quantities, it must not be forgotten that quantity is always quality in a nascent state…" [13].

Massumi's point is taken, though. The tools one employs do have an organic relationship to outcomes. It is just not quite as straightforward as assuming the way tools are made or the materials one uses therefore determine outputs; sometimes results undermine the tools/materials or are used in surprising ways, and it is in the defying of our expectations that the most intriguing work is done. Nonetheless, capturing physical materiality and converting it into digital materiality and then back to the physical manifestations of the digital is now embedded in our artistic methodologies.

There is, however, a great irony to this digital material. It is infinitely malleable, indestructible, and very easily stored. On the other hand, it is incredibly fragile and error-prone. Much digital material is lost in obsolete storage devices, cloud computing, and virtual worlds that have disappeared. And as anyone who has ever had a computer file become corrupted knows a great deal of hard work can disappear in a nanosecond. As well, the ideal of endless storage floating magically in the cloud—in reality server farms located on vast tracts of uninhabited land—has become a critical issue as e-waste and environmental degradation impact our world [14], not to mention increased cybersecurity risk.

4. Analogue versus digital

> *Were all the photographs of a town, taken from all possible points of view, go on indefinitely completing one another, they would never be equivalent to the solid town in which we walk about. Were all the translations of a poem into all possible languages to add together their various shades of meaning and, correcting each other by a kind of mutual retouching, to give a more and more faithful image of the poem they translate, they would yet never succeed in rendering the inner meaning of the original [13].*

The organic relationship between materials/processes and resulting artifact, how our materials and methodologies define what we create, comes into particular focus when considering the difference between that which is analogue in nature and contrarily, the digital. The analogue is an uninterrupted continuum which can never be parsed, whereas the digital is always made up of discrete units even if they are so densely packed or measured as to seem continuous. Analogue we cannot measure in units because there are not discrete moments, but to translate anything into a digital form, we need to measure it in units, zeros and ones, electricity on or off, nothing in between. The units can be pixels, numbers, vectors, or other notations, but nonetheless, they are always bits, quite literally. Zoom into the highest resolution photographic image and you eventually see the individual printed dots translated from the screen pixels that make up what appears to be a smooth continuum.

Contrasting the analogue to the digital has both philosophical implications as well as an impact on artistic methodology. Here again I turn to Henri Bergson to explore the fundamental difference he delineated. A complete discussion of his ideas would be impractical in this text but central to his thinking was what he called the absolute and the relative. Though the analogue and digital are not aligned exactly to Bergson's absolute and relative, his thinking does give us a way to conceptualize these two opposites if compared to his terms. His absolute, "the object and not its representation, the original and not its translation, is perfect, by being perfectly what it is" [13] and one can only know it through intuition. Whereas his relative is "…a translation, a development into symbols, a representation taken from successive points of view" [13] and is analysis not intuition. His absolute connotes the analogue, indivisible, and whole, and his relative the idea of individual digital units, somewhat similar to his "photographs of a town, taken from all possible points of view."

This conceptual understanding does not stop people from trying to construct the analog from the digital. Most digital endeavours seek to imitate the analogue in some way. AR/VR epitomizes this ambition. The photographer Edward Burtynsky, along with his colleagues Jennifer Baichwall and Nicholas de Pencier, recently completed a VR film, *Anthropocene: Ivory Bur*n (2018), shot in the Nairobi National Park, where they endeavoured to capture the fantastical experience of the burning of more than "a hundred tons of confiscated elephant tusks and rhino horns." The torching took place in order "to send a deeply symbolic and visceral message to poachers and illegal trade syndicates" [15]. The filmmakers shot 2,500 still images in order to attempt to recreate a very small part of the event in three-dimensional AR. Tremendous effort and computing power went into stitching these images together and creating a surround environment. The critic Kate Taylor in commenting on the AR compared to the film of the same event points out though that the AR version still is lacking. "In truth, the cinematic version proves more immersive than the still-cumbersome miracles of AR…" [16]. How many more images would the Ivory Burn team need to capture to create more convincing semblance of the analogue? According to Bergson, it could never be anything but "an imperfect translation" [13].

So, what if the digital can never be the analogue and is always an imperfect translation? Are we not getting close enough to fool ourselves into thinking we have recreated the analogue? Here Bergson connects "[t]he real, the experienced, and the concrete" to "variability itself" and further claims that the element or in the case of digital materiality the zero or one, "is invariable" [13]. The implications for artistic methodology lie in the invariability of the element as the building block for creating AR/VR. He goes on to ask "[h]ow could you ever manufacture reality by manipulating symbols"? [13].

Bergson does not necessarily judge the relative although it is hard not to interpret his critique as a fundamental lack within the relative, which he also refers to as a process of analysis. He asserts that analysis "is much more useful in life than the intuition of a thing itself would be" [13]. He is clear that the relative and analysis are as essential to shaping our understanding of the world as the absolute and intuition. However, he equally laments those that "have had no sense of the moving continuity of reality" [13].[2] This might be more of a critique of other theorists, who he labels the "masters of modern philosophy", than the idea that it is easier to understand and valourize our ability to analyze over our embodied intuition.

There is an irony in the discussion of augmented versus virtual reality. By using the digital to evoke the virtual through AR/VR, a spectrum is created that is very much analogue in character; in that it is continuous and indivisible, akin to Bergson's absolute. At one end of the spectrum there is AR, a layering of the digital/virtual on the material world, whereas VR, at the other end, is, in theory at least, a total immersion in virtuality through a headset. However, there are degrees of material imposition throughout the AR/VR spectrum. A completely immersive experience is still only an ideal that anchors one end of the AR/VR spectrum.

So are the two terms AR and VR of any use? They are popularly in play so at some level make a difference to users; however, most people only have the foggiest notion of the distinction between the terms and this may melt away as AR/VR become more embedded in our lives. Dennys Kuhnert and Roger Küng, trainers in the organization XR Bootcamp, theorize that "...anything you learn to do in VR can be applied to AR" and they "also believe strongly that AR and VR will merge together and define the future of computing" [17]. Just the fact that the AR/VR acronym is often written with a slash [18] implies that continuity between the two and the basically indivisible or analogue nature of this spectrum of digital virtuality.

5. The body in the digital virtual

Even in the most immersive of circumstances we need some form of acknowledgement of the physical world around us for the very basic need to keep our bodies intact. For example, there is a safety feature built into a popular VR headset, the HTC Vive, that traces reality as a ghostly wireframe palimpsest so that the headset user is somewhat safe from bumping into walls and falling down stairs. When I first experienced this feature, I was much more intrigued with the wireframe of reality than the VR experience with which I was supposed to have been engaging. A competitor to HTC Vive, Oculus, has developed what it calls a Guardian System for its headset, a telling nomenclature. This functionality allows creators themselves to decide how best to visually hint at the physical world, for example, an overlay of a wireframe box that signals users when they are about to step outside of a zone. Another solution for safety, albeit low tech, is when an attendant is hired to physically and audibly guide VR users to prevent them from hurting themselves. A notable example of this was a VR installation at the Art Gallery of Ontario that allowed viewers to travel through a minuscule, medieval carved prayer bead[3] [19]. The magic of VR was somewhat diminished by the long lineup before donning the headset for a very brief time; and secondly by the constant reminder that someone was by your side limiting your

[2] In a beautifully written paragraph, Bergson complains "...metaphysicians have dug a deep tunnel beneath reality, that the scientists have thrown and elegant bridge over it, but that the moving stream of things passes between these two artificial constructions without touching them" [13].

[3] Ironically enough, technology helped us to feel surrounded by the amazing structure of the prayer beads but as yet conservators are not able to decipher how medieval craftspeople created these miniature complexities. With all our advanced knowledge of design and engineering, the prayer beads remain a miracle.

movement so you did not wander out of the prescribed area and do yourself or others harm. AR/VR systems often are in need of a babysitter to accommodate public interaction for both participant safety and equipment security.

As per this discussion of safety, it quickly becomes perilous to deny the body in AR/VR experiences at the basic level of straight-up survival, but philosophically, it is tricky as well. This is our instrument for knowing and being in the world and the only way we have to divine something like Bergsonian intuition. Academic Andrew M. Cox takes up the question of the neglect of the body in Western culture. In his overview of historical and theoretical influences that feed this disregard, he comes to the conclusion that a focus on the purely digital collapses in the face of "value and meaning in the everyday material and embodied world" [20]. Even though "the rise of the digital seems to reinforce disembodiment" [20]. There is apparently no way around the fact that we are creatures that can only illicit our knowledge of the world through our physicality. The digital, virtual or otherwise, is deeply entwined in our understanding of the world through our bodies. Utopic notions of liberating ourselves from our bodies [21, 22] now register as more and more dystopic rather than desirous.

Disconnect from the body or disembodiment is a contemporary conversation. As undeniable as our bodies have always been, discourse about them is now widely infected by technological concepts. We use the language of the digital in order to understand our own innate bodily processes. For example, people now quite often refer to their brains as hard drives. To quote artist Stephanie Cloutier: "In this present moment we are learning about our bodies again, using our body as memory storage" [23]. À la digital storage, we now believe we are accumulating experiences in our muscles, cells, and nerves that then inform how we think/process *data*. Depending on one's structuralist's beliefs —this vocabulary itself could be changing our minds, thus bodies, supporting the ambitions of the cheerleaders of a post-humanist future.

If we form our world through our physicality, does this make our embodied existence paramount and is this unavoidable consideration of the body a version of essentialism? An illuminating perspective on essentialism comes through feminism. Scholars of feminism have long grappled with issues of the body and how it makes us who and what we are, therefore structuring our experiences. Eventually most deliberations about feminism come back to the question of materialism, a euphemism for this thing we carry around with us called the body. Shivers of terror run-up backs when the still dreaded term, essentialism, is evoked in feminist circles. Intellectual pendulums swing, however, and the most recent iteration of the recognition of the embodiment of women is called material feminism—when ported over to ecological studies—ecofeminism. In their anthology, *Material Feminisms*, scholars Stacy Alaimo and Susan Hekman gather the writing of certain feminist theorists most invested in rethinking 'the materiality of human corporeality' [24]. Arguably, this academic turn to materialism is misnamed. The writers and associated thinkers in the anthology are not debating a strictly essentialist view of feminism, but rather, for the most part, they are looking at the fluidity and continuity between nature/culture, essentialism/constructionism, body/language. But they make a point of noting our detachment from materiality, nature and our bodies. In this sample, Jane Bennett critiques our 'escape from materiality':

> *The philosophical project of naming where subjectivity begins and ends is too often bound up with fantasies of a human uniqueness in the eyes of God, of escape from materiality, or of mastery of nature; and even where it is not, it remains an aporetic or quixotic endeavor [25].*

Likewise we can think of the body and its relationship to the virtual similarly. Imagining the AR/VR without the body is an impossibility. But the body does respond to and adapt to the technology as well. Principally, AR/VR designers have been more than a bit oblivious to the body though the experience is rarely able to escape its reputation as a nausea and headache-inducing trial. The resurgence of the medium took place when the technology of screen refresh and eye tracking had advanced enough so that the majority of people can now withstand this experience for a little while without vomiting [26]. Still, the caveat remains—do not try this on too little sleep.

Another indicative design flaw in virtual reality headsets denies differences between bodies [27]. There is some consideration for the space between the centre of one's pupils or interpupillary distance (IPD) but not much accommodation beyond that. The head strap has a limited ability to adjust and the weight of the set is also prohibitive for people without a typically assumed adult's spinal and neck strength. These are just a few of the obvious disincentives to using the equipment by anyone who differs from the highly idealized male body.

6. Sensorial sensuality

> *The experience of the senses are for real. This direct and unfeigned response was from artist, I'thandi Munro, describing a predominantly VR experience she engaged in but one with hybrid aspects. Munro continued "...I was walking on a piece of real wood and the touch of that wood was significant. I knew I wasn't really in VR because of the touch of the real" [28].*

The implications of essentialism/embodiment for the digital virtual is not just a feminist pursuit, rather it is widely considered. Cox mentions four areas of study that concentrate on the body—phenomenology, practice theory, embodied cognition, and sensory studies [21]. It is through sensory studies that I will consider the organic relationship between the body and AR/VR. Sensory studies contends that our senses are acculturated and extolls "sensual scholarship....research, theory, and methodology that are *about the senses, through the senses, and for the senses* [original emphasis] [29]. A key concept of sensory studies, the sensuous self, the "embodied self is both the material basis and reflexive outcome of perceived sensations and sense-making practices" [29], clarifies how we exist in the world, thus in virtual space. The reference to both a "material basis and reflexive outcome" signals the reciprocal relationship between self and environment. Our sense of self helps to create a VR world in particular where much is required of our sense making or somatic work from very little sensorial input. In return, the self is enlivened by the VR interaction.

Intersensoriality plays a critical part in this notion of cultural sensorial specificity and "refers to the interrelation and/or transmutation of the senses". David Howes delineates four dyads of intersensoriality, each describing a continuum. "a) cooperation/opposition, b) hierarchy/equality, c) fusion/separation, and d) simultaneity/sequentiality" [30]. Put concisely and to quote designer Annika Dixon-Reusz: "We are focusing on one sense at a time, but every sense brings us closer to a full body experience" [31]. Circling back to Bergson and connecting the senses to self, he suggests that one is: "...on the one hand a *multiplicity* [original emphasis] of successive states of consciousness, and on the other a *unity* [original emphasis] which binds them together" [13]. We don't just see when we look or hear when we listen. Unfortunately, our innate intersensoriality holds a dilemma for digital AR/VR.

AR/VR creators and consumers are entranced with capturing what we can sense and converting it into digital materiality. Nonetheless, we can only covert that which we can measure. The number of senses we have are somewhat contested—purportedly even up to 53 [32], however, there are five which are recognized traditionally: vision (sight), audition (hearing), gustation (taste), olfaction (smell), tactician (touch), and four more that are now widely recognized: thermoception (heat, cold), nociception (pain), equilibrioception (balance, gravity), proprioception (body awareness). We have more or less luck with digitizing what we can sense, ephemeral and otherwise, depending whether technologists have figured out how to measure those sensations. Here is a list from easiest to hardest to measure and why:

- vision (sight) can be measured in wavelengths—colour and luminosity—giving us specific numbers that then translate into imagery;

- audition (hearing) is measured in sound waves—frequency and amplitude resulting in sound files—we record this in both midi, the instructions for making sound and actual files themselves;

- thermoception (heat, cold) can be measured precisely in degrees—Kelvin, Celsius or Fahrenheit—so it can be controlled by digital means, though the actual transmission of these sensations is not very satisfactory through a computer interface; and

- tactician (touch) is measured in pressure and force.

These following senses are delivered to us through a complex combination of molecules, making them more difficult to measure than the list above:

- gustation (taste) is difficult to measure as everyone has a different configuration of taste buds but we speak of five tastes—salt, sweet, sour, bitter, and umami; and

- olfaction[4] (smell) is the measuring of smell is almost impossible because of the complexity of how it is delivered through a combination of millions of molecules hitting the nose and how the human receptors for smell absorb and interact with those molecules.

The last three senses on this list are dependent on our brain/nerve reception thus making them extremely difficult to measure:

- equilibrioception (balance, gravity);

- proprioception (body awareness); and

- nociception (pain).

Keep in mind that while some of this sensorial input can be measured, there is no way of knowing how a person perceives it. Computers can theoretically record 16 million colours. The human eye can only perceive 4 million.

[4] One of the most elusive of all the sense abilities to duplicate has been smell. There have been infamous experiments such as the Smell-O-Vision. An article in Wired from 2006 [33] illustrates how hard it is to deliver smell.

Imagery, what we see, is now the most widely developed method for capturing sensorial input. Ironically, as easy as it is to capture, it is extremely complex for a computer to categorize what it has been fed. It takes a human brain to decipher an image, understand it as a whole rather than just a group of pixels of varying gamma and RGB levels. Humans excel at making sense of imagery. However, with the use of artificial intelligence, what I refer to as *collective intelligence*, machines are now better at recognizing images due to the *training* they have received from people. There is a labour force in India, for the most part women, that is, training machines to understand what they see.

On the fringes of the Indian city of Kolkata, in the dusty, crowded neighbourhood of Metiabruz, 460 young women are working at the vanguard of artificial intelligence. The women, mostly from the local Muslim community, are helping to train computer vision algorithms used in autonomous vehicles and augmented reality systems, for the likes of Amazon, Microsoft, eBay and TripAdvisor... The challenge is that the algorithms that underpin the technology are as naive as newborns. They need to be fed millions of labelled examples to teach them to "see" [34]. There remains, beyond sight and hearing, so much of human sensing that cannot be digitized because it is too elusive to measure. This leads to a lack of sensuality and intersensorality in our digital experience. I will expand on this idea but contend that this lack is felt intuitively and causes a craving for sensorial completeness, a yearning.

Turning back to the question of capturing the 'real' world—there is a truism amongst technologists—garbage in/garbage out. The more *real* and complete information we capture, the more we have to work with when we convert it to zeros and ones. More information equals more detail—Bergson's qualitative quantities—in turn, equal more sensuality and richness. Immediately, this enriched sensorial field translates into a deeper aesthetic experience. It has, though, another resonance and that is of heightened affect. Antonio Strati, quoting Michel Henry, claims "there is no sensory activity that is neutral and impassive; sensory activity always involves passion, and every sensation is affective" [35]. AR/VR has its affective and emotional implications which are tied to the abundance or lack of senorial sensuality.

Another truism is that we are really in our infancy when it comes to interacting with machines. For example, we draw with a brick. There are options for using pressure and touch in the digital manipulation of images, such as the Cintiq tablet and stylus. But they are not widely adopted. Emulating what our senses tell us of the outside world depends on the sensitivity of instruments and technology we use to record the sensual experience. There was a time when one could tell the difference between a print of a digital photograph versus an analogue one, but with the addition of megabits of information captured by even the most rudimentary of phone cameras, it is hard for the human eye to discern digital from analogue continuity. So how much more could one capture if there were more sensitive instruments for recording the world around us? And when do we run into the Bergsonian brick wall of the impossibility of the relative translating the absolute? If we cannot discern the relative, can we *fake* the absolute by gathering more and more detail?

7. Tools extensions

In this sense, the elegant term avatar, derived from the Sanskrit avatàra, is most apposite in suggesting the idea of a kind of transubstantiation, the incarnation of life in a different form [36].

One intriguing device for interacting with the virtual/digital realm is both a tool and an extension of self—the avatar. *Avatar* is a Sanskrit word meaning *descent*. It originally connoted the bodily manifestation of a "Hindu god emerging from the heavens… in order to intervene in human affairs." Neal Stephenson in "his science fiction novel *Snow Crash* popularised the use of the word, as it is commonly understood today." Ironically it implies the opposite of its original Sanskrit meaning in that it is a "digital representation in a virtual environment." It can refer to an online name, a profile and/or graphical representation such as photo or animated character "used to represent people in Internet chat, video games, social virtual worlds, massively multiplayer online role-playing games, social networking sites, and other mediated contexts" [37].

Given that on top of being a tool, it is also an image, the avatar goes one better and is an affective, embodied self-portrait. The person/avatar relationship allows for exploring self/other elisions through our affective reactions, wherein we inflect the avatar with *the idea of a kind of transubstantiation*. To paraphrase the philosopher Timothy Morton, who claims "[d]rawing distinctions between life and non-life is strictly impossible, yet unavoidable" [38]—drawing distinctions between yourself and your avatar is equally *impossible, yet unavoidable* and entirely in keeping with human emotional needs. This confusion of self is coherent with a collaboratively imagined world where an avatar is virtually and digitally manifested. I'm proposing an instability, between a subject-creator and an object-avatar, highlighting the *blurriness* in the division of self and other.

Mark Stephens Meadows in his book *I, Avatar: The Culture and Consequences of Having a Second Life*, observes there are three different kinds of avatars; the first is the *dashboard* avatar typified by a static image that accompanies account information or blog entries on forums and sites. This avatar associates an image with a name to add a mnemonically visual aid to an online identity. Secondly, there is a first-person avatar in a console game which is the personification of the player, but is one and the same as the person it represents. Meadows goes on to specify another avatar, "a third level—the second-person camera avatar" where:

> *The "camera" floats above the avatar's shoulder, or behind the head. Like puppets or dolls, they live in architectural space. Like the first-person avatar of the console game, they can run, jump, walk, roll and carry things around, but they are different in that you can, as you drive the avatar, see them do it. These second-person avatars also include the functionality of the first-person avatars as well as the functionality of the profile, or dashboard, avatars [39].*

Meadows gives us an important clue for understanding why there is so much confusion between self and other when considering the second-person avatar. We see this *puppet* or *doll* activated ahead of us. As the *camera*, we walk behind our own selves, somewhat in the manner of an obedient geisha girl or, worse still, a stalker. So, is this semi-autonomous image marching ahead of us? Why are we able to observe ourselves from a god's eye view? As this is only ever available to us in a virtual world while using a second-person avatar, we are confronted by a distorted sense of self and embodiment.

Meadows further theorizes that "avatars are about the advancement of personality within a kind of fiction that is both social and personal" [39]. The avatar must play a dual function of *speaking* back to its maker with some sense of self but also be a representative, an "entity utilized in social environments" [40], a tool for interpersonal interaction. This sense of *toolhood* is further emphasized as the avatar is also the interface to create, build, and design in user-created virtual worlds, thereby fostering even more decentering of this *thing* that is you, but not you; autobiographical character but also functional tool.

Provisionally, I am positioning the avatar as simply an image rather than an *incarnation of life in a different form*. Suggesting the avatar as a fictional character sidesteps the issue of whether it is alive or not, and instead engages with images and our relationship to them by referencing the 'pictorial' and 'effective' turns in theory. The *other-avatar* is a picture/image/icon we have fashioned and *own*: even so, the avatar mechanistically *acts out* on a regular basis, leading us to imagine that it has agency and personality beyond our intentions. The feelings and emotions one has for one's avatar, along with the personal investment, the time and money one puts into creating it, elevate this image to much more than just an arrangement of pixels on a screen.

That an avatar or image-as-avatar is real in the sense of *truth to reality* is taken up in detail in the article "The real problem: avatars, metaphysics and online social interaction". In that text, the author, David J. Gunkel "considers three theories of the real, extending from Platonism to the recent innovations of Slavoj Žižek" [41]. In essence what he is wrestling with is whether our 'real selves' are fiction or not, implying our avatars are built on quicksand. Fair point, but perhaps we need not discuss people or the avatar in this light. *Truth* or *the real* have very little to do with how we *feel* about people or things. So putting aside whether we want to call an avatar real or alive, their existence still reveals our desires, yearnings, fears, and insecurities, not to mention our *impishness* which often plays havoc with our sense of truth. Instead of reviewing the non, posthuman or cyborgian nature of the avatar, I propose a *reading of* the avatar as an animated, performed image and our desire to inject it with subjectivity, while at the same time thinking of it as an object. The avatar entity need not be proven *real* or *alive* for us to feel it is.

Of particular note in the preceding discussion is the subjective instability triggered by the avatar. Similarly the idea of the sublime, which I turn to next, destabilizes boundaries of self. One is overwhelmed and enveloped by the sublime, thus the convergence of subject and object, ironically at the same instance, one stands apart and fundamentally alone. A quote from artist Eugénie Shrinkle supports the idea of a *confusion of self* when discussing in particular the technological sublime: "...a feature of the technological sublime in the digital age is the absence of a consistent and uniform boundary between the self and the machine" [42]. That sounds like an avatar.

8. The virtual sublime

The notion of the sublime has ebbed and flowed since it was first written about by the 1st century CE writer, Longinus,[5] whose text is the first reference we have to the sublime in Western philosophy. Baldine Saint Girons, quoting Longinus, identifies some of the fundamental characteristics: "...for, as if instinctively, our soul is uplifted by the true sublime; it takes a proud flight, and is filled with joy and vaunting, as though it had itself produced what it has heard[6]" and goes on to suggest that this "rapture or ecstasy by storm" is, nonetheless, a "violence" which "is indeed accepted, but it is violence all the same" (Longinus as quoted in [43]). Longinus also claims that "...the experience of the sublime is fundamental in that it brings about a relativization of knowledge" [43]. If a phenomenon is huge, terrible, infinite, and overwhelming, then one experiences the sublime and *knows again*.

Notwithstanding its ancient pedigree, it appears the sublime is still very much alive and kicking; it persists both in popular imagination and academic literature,

[5] It is generally acknowledged that the name Longinus is a placeholder for an anonymous writer. Some references use Pseudo-Longinus or "Longinus" to indicate the uncertainty of authorship.

[6] Saint Girons explains that Longinus's text was actually a discussion of rhetoric and thus references are to the aural rather than the more common visual manifestations of sublimity.

though its nuances have morphed according to different epochs and socio-political contexts. It also has the effect of anthropomorphizing and personalizing phenomena, whether it be natural or manufactured, to the point where what people see/hear/smell/feel/taste resonates deeply inside themselves, making it difficult to extract self from other/nature/technology. This is the crux of understanding the morphing character of the sublime and why it is so pertinent to this chapter—Sensuality, AR/VR, and the Virtual Sublime.

The classic sublime was formed in the heyday of the Romantic era. Since then, in the modern era and particularly in postmodernism, myriad adjectives have been conjoined to it—the classic natural sublime: technological; virtual; feminist; ecological; quantum; to name a few. It is a flexible term, but the notion of terrible awe and overwhelming effect predominate. Of the virtual sublime in particular, Vincent Mosco sums up its mystery and complicated status thus: "… cyberspace has become the latest icon of the technological and electronic sublime, praised for its epochal and transcendent characteristics and demonized for the depth the evil it can conjure" [44]. The virtual shares some characteristics with a classic natural sublime. When faced with the natural, one feels anonymous, alone, forsaken. In the vast tract of the virtual sublime, particularly user-created virtual worlds, there is an equally problematic loss of identity as one navigates a space where one can be anything one wants, but amongst a muddled multitude that only serves to make a person lonelier. As N. Kathrine Hayles puts it, "opening the human to the unthought and unrecognized otherness of a universe much bigger than human conception can hold" [45]. Together with our intrepid avatars, participants are negotiating virtual worlds with a feeling of endless possibility at the same time experiencing the sense of losing self.

One can never really get to the end of a virtual world. It unfolds in front of you and is only contained by the computing power you have or the time you want to invest in the journey. There is no there to get to. This was well illustrated for me by an early encounter I had in the user-created virtual world of *Second Life*. I was approached by another avatar who was attempting to travel to the far reaches of this world. He asked if I wanted to join in the sojourn. Off we went, but then, very quickly on, got trapped dancing endlessly in a disco that we did not understand how to escape other than by turning off our computers and ending the quest. This is indeed a type of infinity, but not particularly sublime.

Along with the psychological implications of the virtual sublime, there is the physical embodiment associated with VR. Immersion is the means of delivering a virtual experience, enveloping the viewer through one's visual and aural senses. One wears a headset to experience true immersion and with these devices come the inevitable physical symptoms. On the positive side, one can fly and float above the world, climb mountains, and dive into the depths of an ocean, all without any auxiliary help in the form of oxygen, external transportation, and protective devices. However, the accompanying sensations of nausea, heart-stopping drops, gut-wrenching twists, sickening feelings can imitate or initiate feelings of mental terror [46]. These are common sensations when negotiating VR through headset technology. Often these experiences fall well short of anything close to the sublime. Nonetheless, if one's stomach drops out when peering over the edge of a platform that is the only obvious structural support in an unbounded sky, then one feels fright and vertigo, which is never far from sublimity.

This concentration on the physical sensations of the virtual sublime do not address the contradiction of the virtual, that is, theoretically at least, a denial of the body. Referencing back to Gibson's *Neuromancer*, one can see the overarching conception of the virtual sublime as a "consensual hallucination." This is all happening in the head which is the promise and mirage of virtuality—we can avoid the inconvenience of bodily functions, such as eating, sleeping, defecating, pregnancy, by figuring out how to exist only in the virtual. What irony that the physicality of a headset existence is perfectly suited to a faux sublime feeling but often the intentions of both theorists and technologists are to rid us of these *unnecessary* sensual reactions. The technology will get better and quit reminding us of our weighted, earth-bound bodies and then one will really be able to experience the true sublime.

9. Yearning

Sublimity troubles our sense of self when one asks what is knowable in the face of enormity, infinity or even the endlessly microscopic. The sublime shakes our normative sense of subjectivity but also reminds us of our boundaries. It is always just beyond our grasp but alarmingly close. Although being infinite, overwhelming, terrible, and beautiful—we still seek out the pleasure and pain associated with the sublime; but instead of nature and uncontrollable expansion outward to the frontier of space, we are turning to digital technology which is deeply disrupting our subjectivity. Though AR/VR virtual worlds are negotiated, often with a feeling of endless possibility, they are at the same time horrendous Möbius strips of existence. Along with the possibility inherent in this affect, there is an added ingredient in the virtual sublime and that is of yearning.

Susan Stewart in her book, *On Longing*, expands on the meaning of yearning desire:

…the direction of force in the desiring narrative, is always a future-past, a deferment of experience in the direction of origin and thus eschaton, the point where narrative begins/ends, both engendering and transcending the relation between materiality and meaning [47, 48].

Here Stewart is making the connections that work so persuasively to argue for a yearning in the digital virtual sublime. Materiality meets meaning and there is a lack. Usually implicit in the sublime is sensory overload. The missing pieces of materiality or truncated intersensoriality in the virtual sublime trigger yearning. As I proposed in the introduction, an AR/VR encounter has an affinity with the sublime but with a deficit of sensorial sensuality leading to less than optimum embodiment and then longing. Perhaps we are grasping at the sublime in order to make up for a lack of sensual input in our digital experience. We need to conjure up some magic again in a digital universe, and sublimity points the way to creative possibility and inspiration. Does the sublime stand in for the thing we crave? Part of the sublime's power is its hallmark, awe. In awe, one is left speechless. In order to be speechless, all our other senses need to be subsumed and overcome.

Most importantly, what does AR/VR mean for our future and why would we go to the trouble of subjecting ourselves to the physical discomfort that often accompanies it? Acceleration into the virtual futurity through strange times such as the worldwide pandemic fulminate questions of sensuality affect and emotional engagement. Can we make AR/VR embodied, fully sensorial, an absolute? Can it give us a full experience of a range of affects, sublimity included? Let's try.

Acknowledgements

The following text benefitted from research I conducted for my doctoral thesis, *Avatar Daughters: Envisioning a Spectrum between the Material/Virtual through Feminist Theory* [1]. I also developed ideas for this chapter while teaching *Interactive Media*, at Ryerson University, Canada. Research for a proposed article for the Canadian Review of American Studies furthered my understanding of virtual sublimity.

I would like to extend a thank you to the support of research assistants, Stephanie Cloutier, Annika Dixon-Reusz, Shiemara Hogarth, and I'thandi Munro, who are fellow team members for the project *Thinking through Craft and the Digital Turn*. They generously offered ideas, anecdotes, feedback, and contributed to the literature review that supported this writing. Specific quotes from them are attributed throughout the article. In addition, Annika Dixon-Reusz looked over the text with an eagle eye and suggested corrections and additional thoughts. This effort was above and beyond, so I would like to express my special gratitude to her. *Thinking through craft and the digital turn* is funded in part by the Social Sciences and Humanities Research Council, Government of Canada.

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Chapter 3

Presenting in Front of a Virtual Audience: A Synthesis of Research in Higher Education

Stan Van Ginkel

Abstract

While previous studies in educational sciences emphasized the essence of feedback on developing students' oral presentation competence, it remains questionable how innovative technologies can successfully deliver high-quality feedback on such a competence. Recent experimental studies in this field revealed the effectiveness of virtual reality (VR) for increasing oral presentation competence and diminishing presentation anxiety. Due to both technological and educational developments, VR systems facilitate the translation of quantitative data into qualitative feedback messages, relating to presentation delivery aspects. This challenges current presentation curricula if the learner is able to individually interpret automatized and personalized feedback messages after rehearsing in front of virtual audiences. As a consequence, it questions to what extent teachers' roles might change over time. This chapter synthesizes recent studies into a set of educational design principles for effective use of VR, discusses practical implications, and provides a future research agenda on this topic for the higher education context.

Keywords: educational design principles, feedback, higher education, oral presentation competence, virtual reality

1. Introduction

Presenting can be considered as a core competence of the higher educated professional [1–3]. It is perceived as relevant for working in various working environments, for career success, and for effective participation in democratic societies [4]. However, young professionals entering working practice often failed to acquire public speaking skills according to the scientific literature as well as evaluations from the corporate sector. Therefore, it is crucial to critically discuss the effective and efficient integration of learning trajectories on oral presentation competence in higher education curricula [3].

A recently conducted review study revealed a comprehensive set of educational design principles for developing oral presentation competence in higher education [3, 5]. Three out of the seven principles directly refer to formative assessment strategies, of which the type of feedback, involving peers in feedback processes, and self-assessment are named as crucial learning environment characteristics. Although several empirical studies, aiming to further refine these principles, mentioned the teacher as a crucial feedback source, it might be questioned to what extent innovative technologies, such as VR, could play an essential role in both (1) facilitating presentation rehearsals and (2) providing feedback to the individual learner.

Follow-up research showed that students' oral presentation competence can be developed by the use of VR [6]. However, still the role of the teacher remained crucial, since the produced data reports, delivered by the VR system, needed to be interpreted by the teacher into feedback messages for the student. Recent developments in technology and education managed to translate the quantitative data into qualitative feedback messages on presentation delivery aspects. As a consequence, current designers of presentation curricula are challenged if the learner is able to individually interpret automatized and personalized feedback messages after rehearsing in front of virtual audiences. In line with this, it questions to what extent teachers' roles might change over time.

The goal of this chapter is to synthesize recent studies into a set of educational design principles for effective use of VR, to discuss practical implications and to construct a future research agenda on this topic for the higher education context.

2. VR and developing oral presentation competence

Previous studies in this field emphasized the benefits of using VR to reduce presentation anxiety in the higher education context [7, 8]. These studies revealed that if students present in a virtual environment, they report lower self-reported levels of anxiety. Further, researchers showed that the degree of anxiety experienced by the presenter depended on the type of virtual audience. In line with this, a hostile, negative audience demonstrated a strong effect on students' perceived presentation anxiety [8]. Other researchers focused on the relationship between VR and students' development of oral presentation skills. It was found that immediate feedback could positively impact students' evaluation if sparse feedback strategies were provided instead of continuous or no feedback at all [9]. In that study, feedback was delivered by a color-coded gauge above the audience. Further, another study proved that interactive audiences in VR encouraged students' development of presentation skills [10].

Although several studies focused on the relationship between VR for delivering feedback and reducing presentation anxiety and developing oral presentation skills, cognition and attitude towards presenting were not included within the research foci. Following the construct of competence, it is stated that if students acquire more knowledge about presenting, their presentation behavior might positively develop and as a result also change their attitudes towards presenting [3]. Further, previous researchers studied immediate feedback on presentation delivery aspects within VR, while delayed feedback verbally provided by a presentation expert can be considered as an essential type of feedback in realistic presentation skills curricula. Another bias of the described studies is that the feedback is solely provided within the system. However, it remains questionable to what extent VR is as effective as presentation experts providing their feedback based on observation and interpretation of students' actual behavior. Finally, students' perceptions with regard to the use of VR and the provision of feedback based on these systems have scarcely been researched. Therefore, it is crucial to include this crucial intermediate variable for encouraging learning processes and outcomes in follow-up studies.

Taking the mentioned gaps in presentation literature on VR into consideration, a recent experiment studied the effectiveness of a VR-based presentation task, in which students received feedback after the presentation rehearsal in VR—on eye contact, use of voice, posture and gestures—that was traced by the VR system

Figure 1.
Presenting in front of a virtual audience in the television studio of "Presenting with Impact." ©Kees Rutten.

and interpreted by a presentation expert [6]. The results showed that the three components—cognition, behavior, and attitude towards presentation—increased significantly without a difference in impact between the experimental and control conditions consisting of a face-to-face presentation with only an expert feedback. In addition, a self-evaluation test showed that students from the experimental group highly appreciated the analytical and detailed characteristics of the VR feedback and at the same time shared suggestions regarding the integration of VR in higher education. With regard to the scientific relevance of that study, integrating both forms of feedback (VR and face-to-face feedback) could further increase the quality of feedback messages and as a result impact students' learning outcomes focusing on presenting. In line with this, educational design principles relating to the type of feedback could be further optimized.

Recent developments in innovative technologies as well as in pedagogical and educational sciences revealed that feedback messages can be constructed by the VR computer system and delivered to the individual learner [6]. At the same time, recent trends in educational practice underscore the need to encourage personalized learning in which learning environments directly match learners' needs and individual preferences, to adjust learning environments just-in-time and to facilitate opportunities to practice and to deliver feedback irrespective of time and place [6]. Taking the earlier published comprehensive set of seven educational design principles for developing oral presentation competence in higher education into account, how can virtual learning environments further optimize existing principles, such as instructions, learning activities, and formative assessment strategies, in order to create more effective, efficient, and challenging learning trajectories fostering students' presentation competence in higher education curricula? (**Figure 1**).

3. Towards a set of principles for VR on presenting

This section focuses on constructing seven educational design principles for optimizing students' development of oral presentation competence by making use of VR. The first sentence of each paragraph formulates the particular design principle followed by conceptual and empirical argumentations.

First, learning trajectories fostering students' presentation competence in VR should directly relate to personal learning objectives of the individual learner. As emphasized by studies in presentation literature, learners vary with respect to their learning needs and preferences [2, 3]. For instance, some students need to develop their use of voice, and others should use more supportive gestures during their presentation. In regular presentation skills courses, it is considered as a challenge for teachers to differentiate between students with varying objectives partly due to time constraints. However, VR environments can facilitate opportunities to practice and to rehearse irrespective of time and space, at students' own preferred pace and potentially without the intervention of a presentation expert. These developments foster personalized learning and could create more effective as well as efficient learning environments.

Second, presentation learning paths should be positioned just-in-time prior to an authentic presentation task. Normally, face-to-face presentation courses are being provided at a fixed moment in time without a specific connection to a final, authentic presentation task [3]. If mobile, personalized learning environments in VR are facilitated prior to a presentation task for a real client, it could impact the motivation of the individual learner and as a consequence foster the development of students' oral presentation competence [3]. Positioning presentation activities in VR prior to a performance for a real audience, for example, in the context of an internship, might also increase the perceived relevance resulting in more effective student learning.

Third, presentation learning environments should incorporate varying types of non-expert and expert models. In current face-to-face presentation courses, students acquire knowledge on presenting by observing non-expert models such as peers. However, the presentation literature revealed that both non-expert and expert models can foster students' self-efficacy towards presenting [3]. Further, expert models show different types of performances with regard to eye contact, use of voice, and posture and gestures. In line with this, within VR environments, learning activities can be integrated, focusing on developing presentation behavior based on preferred expert models. Finally, learners in VR can compare their own performances on presentation delivery aspects to the averages of world leaders, CEOs, or television personalities.

Fourth, learning trajectories towards presenting should facilitate opportunities to practice in varying environments. In face-to-face presentation curricula, one of the challenges for teachers is to provide rehearsals for students, especially in times when opportunities for teacher-student interactions are diminishing. Virtual reality facilitates practicing presentations in front of interactive audiences in varying contexts, such as classroom settings, theater environments, and television studios. Although previous researchers claim that a two-presentation sequence is required, other presentation experts suggest that students need at least four or five rehearsals in order to significantly develop their behaviors [11, 12]. Practicing in front of virtual audiences in different contexts is considered as one of the crucial principles for virtual learning environments fostering students' presentation competencies.

Fifth, students should receive immediate and delayed feedback messages on their actual presentation performances. A recently conducted experimental study revealed that feedback from VR systems can be characterized as detailed and analytic, while face-to-face feedback from teachers concerns positive and constructive messages [6]. Combining these insights and relating these to the main quality criteria of feedback could facilitate the construction of personalized high-quality feedback messages fostering students' presentation skills [13]. Further, another study revealed that immediate feedback is as effective as delayed feedback; however, this type of feedback is especially effective for enhancing aspects such as eye contact, use of voice, and posture and gestures [14]. During presentations in front of virtual audiences, icons can be projected above these avatars informing the presenter on the extent to which they make eye contact with all audience members and their speech rate.

Sixth, students should have the opportunity to receive feedback from external feedback sources such as peers. Previous research revealed that triangulating feedback mechanisms allow for greater reflective learning [3]. Further, students that are actively involved in their learning processes and work collaboratively could feel a higher sense of responsibility and an increased attention to the performance criteria and as a result foster their presentation skills. However, the provision of peer feedback in regular educational face-to-face systems is limited. By making use of VR, students can deliver and receive feedback irrespective of time and space. Further, it could also increase the authenticity of the situation. For example, if students are required to present in English and their peers are from another country, it could increase their motivation and as a consequence also their performances.

Seventh, reflection activities facilitate the development of students' oral presentation skills. Students' reflection on their own behavior can be considered as essential for student learning [15]. However, quasi-experimental studies revealed that self-assessment tasks revealed a limited impact on students' attitude towards presentation and the actual presentation skill [3, 16]. Essential argumentations refer to the lack of an external feedback source, the complexity of reflection cycles, and a lack of active reflection of the individual student [3]. VR could optimize the principle of self-assessment tasks for presentation skills development, since feedback can be delivered by the system and learning trajectories are adapted based on the input of the individual learner. Further, students can practice in front of virtual audiences without the need to be actually in environments such as classrooms, theater environments, and television studios.

4. Practical implications for effective use of VR

Research on VR fostering presentation competence combined with recent developments in technology and education facilitated the design of a mobile, personalized, and comprehensive learning environment in VR. The following advantages for student learning can be formulated: (1) the environment relates to the personal learning objectives of the individual learner, (2) the student is able to use this VR tool for developing presentation skills just-in-time, and (3) presenters can individually rehearse their presentation performances as many times as they need and receive feedback by the VR system during or after every single presentation.

While teachers and teacher educators in varying countries, such as the Netherlands, Italy, Thailand, and the United States, are experimenting and integrating this VR tool in educational practice, several challenges appear so far.

First, teachers are challenged to critically rethink their presentation curriculum if certain parts can be facilitated by the VR system. Examples refer to (1) working with individual learning objectives, (2) learning from instructions, (3) observing presentation models, (4) rehearsing in front of different environments, and (5) receiving immediate and delayed feedback on performances.

Second, teachers are challenged to design more effective self-assessment tasks with the support of VR. In line with this, more information of the individual learner can be traced, such as big data, by monitoring their learning processes in VR. This challenges the teacher not only to act as an instructor within presentation curricula but also to further support their role as coaches by making use of both observations and interpretations and analyzing detailed information about presentation delivery aspects facilitated by the VR system.

Third, teachers are also challenged to co-design such virtual learning environments because their educational expertise and experience are key for making effective use of VR. Since expertise from several domains, such as ICT, communication, and education, is needed in order to effectively develop these environments, teachers and teacher educators should collaborate with professionals from varying domains and sectors.

Nevertheless, several implications for educational practice remain with regard to implementing VR in presentation education. Integrating VR in education means that teachers, teacher educators, curriculum designers, and coaches need to be trained before entering formative assessment processes supported by VR. Finally, working with VR means, initially, investments in terms of effort, time, and financial resources that should directly relate to strategic policies of higher education institutions [6, 17].

5. Constructing a research agenda on VR and presenting

The following section describes five directions for future research and sets a research agenda for developing oral presentation competence supported by VR in higher education. These directions are built on the gaps concerning the foci of previous VR studies, inconsistencies in empirical and conceptual findings, and the quality of empirical evidence, taking into consideration the related study designs of the reviewed publications.

First, recent technological developments managed to convert quantitative information from the VR system into qualitative feedback messages that directly relate to the standards for high-quality feedback in presentation research [13, 18, 19]. In line with this development, the question is to what extent the presentation expert (the teacher)—as a crucial feedback source—can be replaced in certain parts of the feedback process [20]. Therefore, an empirical study should be conducted within a realistic educational setting in higher education and focuses on the impact of qualitative feedback messages in a VR system on the development of students' ability to speak in public. Such an experimental pretest posttest study examines to what extent the development of students' cognition, behavior, and attitude towards presentation depends on an experimental condition in which students present in front of a virtual audience and receive automated feedback that can be interpreted individually. The effects are suggested to be compared with a control condition in which students present in VR and receive feedback based on the VR system that is interpreted by the teacher. Mixed methods, such as knowledge tests, validated rubrics, and self-evaluation tests, should be used for data collection [16]. Such a study contributes both to presentation research and educational practice, since insights from this study could lead to a further refinement of educational design principle 5, with regard to the type of feedback, as previously emphasized by researchers in this field [3, 21]. Moreover, the results of the study provide insights about how teachers' roles might change in formative assessment strategies in the higher education context with regard to ensuring personalized and automated feedback.

Second, previous studies revealed that self-assessment tasks have limited impacts on students' development of oral presentation competence in the higher education context [3, 15, 22]. The question is whether the development of personalized learning environments in VR can enhance the quality of self-assessment tasks in higher education, since students can now (1) adjust their learning trajectory to their personal learning objectives, (2) use these VR environments just-in-time, and (3) practice their presentation skills and receive unlimited feedback. A longitudinal study should focus on students' data obtained by the VR system. Mixed methods, consisting of quantitative analyses of VR data and qualitative research (including observations and in-depth interviews), are suggested to be used to (1) describe the learning processes of students in VR, (2) monitor the reflection processes of the individual students with the aim of strengthening self-assessment tasks in presentation education, and (3) test the relationship between (a) reflection processes of students and (b) learning outcomes focused on presenting in VR [3].

Third, previous studies emphasized that at least a two-presentation sequence is required for students to effectively develop their oral presentation competence [2, 6, 11]. However, it remains questionable how the development of students' performances behaves after their second presentation. In the context of a business curriculum, researchers studied the optimal number of presentations and concluded that a significant increase in performance can be traced between the first and second presentation, though a three-presentation sequence revealed no significant benefits. This might be caused by the fact that students past the apex of the classical S-shaped learning curve [11]. Other researchers, however, claimed the integration of four or five performances in presentation curricula [12, 23]. These findings should be interpreted in the light of domain-specific face-to-face presentations assessing solely presentation skills instead of taking other core components of the construct of competence, such as cognition and attitude towards presenting, into account. Further, facilitating students' presentations in curricula can be considered as a time-consuming activity. Therefore, future research should test the hypothesis of the two-presentation sequence, scarcely supported by empirical studies in presentation literature, by integrating VR in realistic educational settings. Future experimental studies could distinguish between several conditions, such as a one-presentation, two-presentation, and three-presentation sequence, and verify potential differential impacts on students' oral presentation competence in higher education.

Fourth, a previous study on VR and the development of students' oral presentation competence emphasized the limitation with regard to students' unfamiliarity with adopting VR for learning purposes [6]. This could have influenced the results of that study, both in terms of impacts on developing presentation competence and perceptions towards using the innovative technology [24]. For example, certain students might have perceived the use of VR as motivating, while other students might have experienced the use of VR as evoking their presentation anxiety. Therefore, longitudinal studies could reveal if oral presentation competence can be influenced if participants first become more familiar with the technology and whether students' perceptions change over a longer period of time while using VR.

Fifth, future studies should focus on testing the generalizability of the constructed and formulated set of principles in this chapter with regard to different student characteristics. Since researchers in this field reported that students could differ in their perceptions of VR depending on their preferred learning activities, it is suggested to incorporate the following characteristics in future experimental study designs: (1) students' traits (such as gender, age, and educational level), (2) experienced versus non-experienced students regarding presenting in VR, (3) students from different sociocultural traditions (e.g., teacher-centered versus student-centered higher education curricula), and (4) students with varying personal goals or learning patterns that influence their perceptions of the value of feedback types for developing presentation competencies [25].

6. Conclusion

This chapter aimed to synthesize previous studies into a set of educational design principles in VR, fostering students' presentation competence, to discuss practical implications and to construct a future research agenda on this topic. Optimizing earlier formulated principles could develop a theoretical framework situated in the context of VR for presenting to direct intervention and empirical and theoretical studies. Besides studying the optimization of the formulated principles, future studies should test the generalizability of the set by taking student characteristics, their perceptions, and sociocultural backgrounds into consideration. In line with this, it remains questionable to what extent this set of principles can also be adopted to foster other academic and communication competencies in VR, since comparable learning environment characteristics are visible for developing argumentation, negotiation, and scientific writing skills. Future scientific and practical research should also take the recent developments of technological and educational trends into account in order to create both effective and efficient virtual learning environments in higher education in which high levels of ecological validity are guaranteed.

Acknowledgements

This work was supported by a research grant of the University of Applied Sciences Utrecht. Within the VR project on developing oral presentation competence, the following partners collaborated: (1) VR-Lab of the University of Applied Sciences Utrecht, (2) CoVince Adventurous Learning, and (3) partner schools of the NOA Group in Amsterdam.

Conflict of interest

None of the authors or partners in the project report any conflict of interest.

Informed consent

Informed consent was obtained from all individual participants in the reported studies.

Notes

The authors would like to thank photographer Kees Rutten for producing the picture for this project.

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Chapter 4

Virtual Reality: A Tool for Improving the Teaching and Learning of Technology Education

Onele Nicholas Ogbonna

Abstract

This work dealt with technology education, its expectations and present state, especially in developing countries. It looked at virtual reality: its development, types, uses and how it can be applied to improve teaching and learning. It also looked at different works that compared virtual reality, and other educational technology tools were reviewed. Advantages of virtual reality were highlighted; these will include both social and academic issues. Immersive and non-immersive virtual reality for education were briefly discussed, looking at the applicability of each to teaching and learning, ease of use, cost-effectiveness and health implications.

Keywords: virtual reality, technology education, virtual environment, virtual reality components, educational technology

1. Introduction

Technical Vocational Education and Training (TVET) is a globally recognized process for preparing people for dynamic engagement in occupations of functional value. It is an effective source of skilled workforce. It is an effective tool for employment generation, wealth creation and crime reduction. UNESCO [1] defined TVET as all forms and aspects of education that are technical or vocational in nature and skill oriented, provided either in educational institutions or under their authority, by public authorities and private sectors or through other forms of organised education, formal, informal or non-formal, aiming to ensure that all members of the community have access to the pathways of lifelong learning. TVET is defined as an integral part of general education which prepares its recipients for occupational fields and effective participation in the world of work. It is an aspect of lifelong learning and a preparation for responsible citizenship, which helps to promote environmentally sound sustainable development and facilitate poverty alleviation. The goal of TVET is to fight indolence, develop skills, provide knowledge and build attitudes required for entry and progressing in any chosen occupation.

However, TVET today faces huge demands globally due to high level of unemployment. Access to skill acquisition is low in relation to the potential trade. High educational entry requirements exclude the majority of youths and young adults. Female participation is relatively low in TVET and concentrated in female-dominated occupations. Geographical imbalances also exist—with low enrolments in rural and low-income areas [2]. The quality of TVET graduates has been portrayed as extremely low, as the majority graduate without employable skills. They lacked the applied technical skills necessary for solving problems and enhancing business productivity and knowledge required by industry. Therefore, they cannot take advantage of available employment opportunities; neither can they create employment, due to gross skill deficiency [3]. Low performance of candidates on terminal examinations is symptomatic of low quality. And symptoms of faulty TVET training include mismatches between supply and demand, employer complaints and low employment rates for graduates. For TVET to achieve its envisaged objectives, it must be properly strengthened (UNESCO, [4]; United Nations, [5]).

The infrastructure needed to deliver quality and practical oriented TVET courses requires huge investment in capital. Both hard and soft infrastructure is needed to prop up the system. Challenges of attaining quality TVET programmes have been discovered to include lack of required TVET facilities, poor funding of TVET programmes and the use of obsolete facilities. Inadequate funding may have been indicted in the poor infrastructural support needed to drive quality delivery of TVET courses [3]. This limitation frustrates the integration of entrepreneurship and practical skills in TVET programmes especially in developing countries. The lack of support infrastructure and infrastructural failures results to high transaction costs which makes delivery very expensive, and since economy has not been friendly, inefficiency has prevailed.

Puyate [6] pointed out that the present state of vocational and technical education facilities is very poor; there is no planned means of maintenance of the already broken-down equipment or means of purchasing new ones, and there is little or no concern on the part of government, teachers and students for the improvement of the present state of teaching facilities. This limits effective skill acquisition by students leading to production of unskilled TVET graduates who cannot fit into gainful employment. Surveys show that only about 40% of TVET institutions of higher learning have laboratory or workshop space for technical education programmes and that the other 60% do not have laboratory or workshop space and that this reflects the low quality of technology programmes in higher institutions. He further noted that these few universities that have laboratories experience acute shortage of laboratory equipment and supplies. Puyate (4) concluded that this situation is partly responsible for the reason why it has been increasingly difficult to run experiments effectively for students and made the teaching and research in science and technology difficult, and therefore the country was producing insufficient and ill-prepared technical education graduates necessary for driving the technological and socio-economic development of this nation. Uwaifo [7] lamented that due to inadequacy of instructional facilities, only a small proportion of the students benefit from the current pedagogical system used in developing countries like Nigeria, especially in technical and vocational education. Unavailability of facilities has caused the use of ineffective methods of teaching and learning. There is dearth of ICT facilities for the training of students. Access to affordable and reliable Internet connectivity is only available in a few institutions, faculties and offices, and power fluctuations and deficient bandwidth have considerably reduced reliability of the access and made things difficult [7].

There are basically two branches of TVET: the technical and vocational areas. Effective teaching and learning of any branch of technical and vocational education can be made easier and interesting through the use of appropriate and adequately provided learning facilities as well as the adoption of the right teaching and learning methods. Inadequacies in teaching, as well as laboratory and workshop facilities, have contributed in no small measure to the diminution of the quality of technical education graduates. Uwaifo [7] lamented that only a small proportion of the students benefit from the current system used in technical and vocational education, proving that only those who learn easily if information is in written or spoken form (verbalizers) can learn in the present situation. This calls for a more effective method in an encouraging environment. Virtual reality has been found effective for learning in different fields and for different types of learners.

2. Virtual reality

Virtual reality is a computer-generated, three-dimensional, multimedia environment. Virtual reality is an environment produced by a computer that looks and seems real to the person experiencing it [8]. It means experiencing things through computers when such things did not really exist [9]. It is a simulation of a real or imagined environment that can be experienced visually in the three dimensions of width, height and depth and that may additionally provide an interactive experience visually in full real-time motion with sound and feedback [10]. Virtual reality, therefore, is a computer-simulated, game-based learning environment, which appears real and gives learners the opportunity to interact with the learning materials and share learning experiences with both their teachers and other learners. In virtual reality, human participants can engage and manipulate simulated physical elements in the environment and interact with fictional or simulated components. Virtual reality allows the user to perform actions and observe their consequences but without penalties as experienced in real situations.

Virtual reality can be traced back to the nineteenth century. The term "virtual reality" was first used in the mid-1980s when Jaron Lanier, founder of VPL Research, began to develop the gear, including goggles and gloves, needed to experience what he called "virtual reality." But before then, some technologists were developing simulated environments. A major landmark was made in 1956 when the Sensorama was built. Morton Heilig was interested in using it for the Hollywood motion picture industry. He wanted people to get the feeling of being in the movie. The Sensorama experience simulated a real city environment, which one could ride through on a motorcycle. The rider experiences a multisensory stimulation, which provides the opportunity to see the road, hear the engine, feel the vibration and smell the motor's exhaust in the designed virtual world. In 1960, Heilig patented a head-mounted display device, called the Telesphere Mask.

In 1965, another inventor, Ivan Sutherland, built upon the foundational work of Heilig to achieve "the Ultimate Display," a head-mounted device that he suggested would serve as a "window into a virtual world." The 1970s and 1980s were a heady time in the field. Optical advances in the 1970s and 1980s produced haptic devices and other instruments that would allow you to move around in the virtual space. For example, in the mid-1980s, the Virtual Interface Environment Workstation (VIEW) system was built by NASA to combine a head-mounted device with gloves to enable the haptic interaction.

The evolution of virtual reality has provided means of carrying out experiments which would not otherwise be possible owing to availability, accessibility and cost of equipment, tools and materials, as well as safety of human and material resources. Although virtual reality does not replace real objects, it helps to carry out experiments before it is done in the real world. It has been proven to contain a feature which appeals to every faculty of learning. Virtual reality can be used to simulate a real environment for training, education and an imagined environment for interaction [9]. Virtual reality proved effective when used to augment physical facilities for learning in many fields, like teaching architecture [11]; teaching physics [12]; welder training [13]; teaching painting [14]; teaching physical education [15–18]; training in fire safety [19]; teaching safety rules [20–22]; teaching electric power supply systems [23]; teaching biology [24]; and teaching electronic circuit construction [3], among many others. In virtual reality, students can work at their own pace to master the skills needed, get periodic feedback and have the opportunity to correct their mistakes without loss of materials, damage to equipment and injury to human beings and materials [25]. Virtual reality provides an opportunity to accurately and realistically simulate dangerous or risky situations and make them safe for learning before engaging in the real situation. Virtual reality can deconstruct complex procedures into convenient actions with each student learning at a different pace [26]. It helps in visualisation of complex concepts and theories as well as exploration of virtual scenarios in the form of real-world settings. It stimulates interaction, ensures that learning is fun and enjoyable and permits cost-effectiveness [27]. Virtual reality encourages students' participation, reduces distractions and increases attention span of students. By doing so, learning of technology education may become a more interactive process, playful and experimental—like the action-oriented approach of learning. The fondness of young people on computer games gave credence to the adoption of virtual reality as an educational tool [3, 28, 29] for teaching and learning of technology education.

There are two principal ways of using virtual reality in the classroom. The first way involves a traditional desktop set-up. This form of virtual reality is called desktop, fish tank [30, 31] or simply non-immersive virtual reality [3] and used interchangeably in this study. Desktop virtual reality is presented on an ordinary computer screen and is usually explored by keyboard, mouse, wand, joystick or touch screen [32, 33]. The second way is the immersive system. Immersive virtual reality is presented on multiple, room-size screens or through a stereoscopic, head-mounted display unit [34]. Additional specialized equipment such as a data glove enables the participant to interact with the virtual environment through normal body movements. Sensors on the head unit and data glove track the viewer's movements during exploration and provide feedback. This environment may take the form of a series of large screens or a complete cave automatic virtual reality system [35].

Desktop virtual reality is quite affordable as compared to immersive virtual reality, thereby making the choice suitable for studies in medium-income economies as experienced in developing countries. Besides, there is no overwhelmingly conclusive evidence that immersive systems are more effective in educational applications than their non-immersive counterparts [34]. Rather, the non-immersive virtual reality is much more mature and widely used in different educational areas as compared to the immersive virtual reality which is cumbersome, expensive and occupies much space [36]. Studies have shown that desktop virtual reality technology can enhance academic achievement [3, 37–40]. Moreover, there are unresolved questions relating to health and safety issues, such as motion sickness, simulator sickness and perceptual shift that arise in the use of immersive virtual reality systems [41–43]. Literature revealed headaches, nausea, balance upsets and other physical effects of head-mounted device systems. One other concern is the potential side effects and after effects of virtual reality exposure. Some other effects could include cybersickness, a type of motion sickness caused by the virtual reality experience, perceptual-motor disturbances, flashbacks and generally lowered arousal [44]. Desktop virtual reality is user friendly. Woodford [9] emphasised that desktop virtual reality is collaborative, unlike its immersive counterparts. Collaboration is a vital aspect of effective learning in skill-related fields like technology education.

Youngblut [36] conducted an extensive survey research on educational uses of virtual reality technology. Youngblut's study found unique capabilities of virtual reality in boosting academic achievement. This study showed potential educational effectiveness even for students with special needs. The role of the teacher changed from director of learning activities to facilitator. It was reported that students enjoyed using predeveloped applications and developing their own virtual worlds. The majority of the teachers in the studies reviewed said they would use virtual reality technology if it were affordable, available and easy to use for students and teachers. Chen [45] carried out an experimental study titled "Virtual Space and Its Effects on Learning." The aim of the study was to find out how virtual reality can influence the learning of technology skills. The study showed that virtual reality is an effective tool for teaching and learning skills. However, Chen [45] asserts that although virtual reality is recognized as an impressive learning tool, there are still many issues that need further investigation including identifying the appropriate theories and/or models to guide its design and development, finding out whether its use can improve the intended performance and understanding and investigating ways to reach more effective learning when using this technology and its impact on learners with different aptitudes. Lee et al. [24] researched on learning effectiveness in a desktop virtual reality-based learning environment. The learning effectiveness was measured through three specific purposes: academic performance, perceived learning and satisfaction. There was a significant difference in the academic performance, perceived learning and satisfaction between the two groups. It was concluded that the virtual reality instructional programme positively affected the students' academic achievement and their perceived learning quality and satisfaction. The study of Lee et al. [24] helped to justify the desktop virtual reality for this study.

Onele [46] carried out a study on effects of teaching methods in virtual reality on the interest and academic achievement of electronic technology education students in Nigerian universities. It adopted a pretest-posttest quasi-experimental design. ElectricVLab designed and supplied by Quality Assurance International LLC, Massachusetts, in the USA, was used to provide the virtual learning setting for students to learn electronic technology education. The study found that student achieved high with virtual reality; there was no significant difference between the achievement of male students in demonstration and their counterparts in peer tutoring class. However, female students in peer tutoring class achieved significantly higher than their counterparts in the demonstration class. Moreover, students from both classes indicated high interest in the study of electronic technology education using virtual reality. The research identified a significant interaction effect between teaching methods.

It is true that virtual reality has existed for decades; its use is new to education, especially in developing countries. Research on applications of virtual reality technology to education is in its infancy, especially in Africa [47], and for teaching and learning in industrial-related training like technology education [3]. Such a situation presents both challenges and opportunities for instructors and researchers interested in virtual reality technology. One of those challenges is the selection of right teaching methods when virtual reality is involved. Some of the studies were on how to arrange lessons, how these arrangements affect students' behaviour, and in the long term, how they affect students' academic achievement. Yet, there does not seem to be a sufficiently conclusive and prescriptive body of research to guide the instructional method and classroom facilitation of virtual reality technologies [3, 48–51]. Researchers lamented dearth of empirical evidences to help instructors make the right choice of teaching methods in virtual reality [52–54]. Thus, researchers and educators interested in classroom uses and methods in virtual reality technologies do not yet have either a sound theoretical framework or a strong body of empirical data from controlled experiments with which to work. Anderson [55] believes that the use of virtual reality as a learning environment will require a thorough pedagogical consideration by educators in order to choose the most appropriate and suitable teaching methods, especially for teaching and learning of technology education.

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Chapter 5

Industrial Heritage Education and User Tracking in Virtual Reality

Vladimír Hain and Roman Hajtmanek

Abstract

Industrial heritage provides one of the most important records of social and technological progress and has international potential for education and development. This chapter presents the potential to use the virtual reality devices for informal education in technical and natural sciences. The hypothetical virtual appearance of an industrial power plant from the nineteenth century in Slovak city of Piešťany was intricately reconstructed by a combination of identified conserved valuable parts of the building and preserved original equipment and archival plans. This practical result—interactive virtual tool—educates about the lost heritage by allowing viewers to look closer and experience the former atmosphere of industrial work. During the virtual visits, users are motion tracked and invited to take photographs to mark the most interesting motives. Gathered data from this users' observation were analyzed to find behavioral patterns and to give feedback information about the exhibition's attractivity, used in further presentations.

Keywords: education, virtual reality, industrial heritage, old power plant in Piešťany, user tracking

1. Introduction

In museums of technology around the world, there are innovative creations of the human spirit that are no longer interesting. The current trend, therefore, is the development of interactive models of the presentation of natural laws and technology—those that are capable of making technology museums more attractive and of enabling the inspiring use of this rich source of knowledge.

Virtual reality (VR) is one of the most progressive, quickly evolving segments in information technology. The research team at the Faculty of Architecture STU BA systematically addresses the issue of virtual reality and seeks practical applications in several engineering areas and technical education [1]. The potential of virtual and augmented reality was identified and verified in terms of derelict monumental buildings—specifically industrial heritage.

"The concept of monument presentation was extended from prevailing historical or artistic significance to other meanings, such as less important architectural examples although important in terms of social or technological concept. These events often support industrial heritage" [2]. Industrial monuments are still highly regarded by society. Raising awareness of industrial heritage could help society to protect its history.

The case study introduced in this chapter is additionally a part of the research focused on the using of virtual reality as an analytical tool of design. This way is the exploration of new simulation techniques and educational qualities of virtual spaces connected to the gathering of information about users in defined spatial conditions and subsequent utilization of these data in the further design process.

2. Theoretical scope

Several historical buildings no longer exist but historical documents—archive technical documents, drawings, or photographs—have been preserved. Some buildings remain in the living memory of earlier generations or have preserved few physical fragments. Some have been irretrievable destroyed—removed and replaced by new buildings. This historical documents and preserved parts of the building may offer data for a virtual presentation of the extinct significant building or historical monument. The presentation of a hypothetical reconstruction by virtual reality can serve to bring the history, culture, and technology closer to the public [3]. The presentation of the digital model can serve as a graspable presentation of the extinct technical and cultural heritage.

In the game industry, the degree of "realness" is referred to the notion of immersion. Immersion is meant as transportation (presence) rather than as absorption [4]. The presumption is that new virtual reality environments with their high fidelity and real-time interaction have higher degree of immersion than conventional physical 3D models. The high degree of immersion of the VR environment is substantial in increasing the effectiveness and attractiveness of education, which is closer to our innate learning by experience. Besides that, with the rising of the degree of immersion, it is easier to compare user experience to real situation, allowing to gather relevant data about user behavior.

The user tracking within historically long spatial cognition research is based on K. Lynch's image of the city [5] and W.H. Whyte's urban cameras [6] and continues with later explorations as A. Mallot's experiments with orientation in virtual environments [7] and C. Ratti's real-time Rome [8]. These studies showed that user tracking is a high-quality source of information, describing certain behavioral patterns. All these experiments tracked human behavior to use it as feedback for further design. However, this new knowledge was not utilized in any practically used analytical tool, e.g., B. Hillier's space syntax [9]. This tool, on the other hand, works only with theoretical outcomes of the spatial cognition; it is not implementing the real tracked data [10]. The case study in this contribution is focused on utilization of tracked behavior in analytical tool for evaluating further virtual exhibition designs and presentation spaces. For that further application, it is crucial to induce natural behavior of users during the tracking phase by introducing them the right motivation and reward. A motivation is behavior translated from the real world (e.g., exploration of real machinery hall). This motivation is supported by reward, which is related to the real; that is, it has impact on the real. As our previous experiments have shown, this system induces natural behavior of users and convinces them to interact and be part of the scenario [11].

3. Methodology

3.1 Research materials

This paper reviews implemented systems and describes application of VR in presentation of old power plant in Piešťany, which is Slovak industrial heritage (**Figure 1**). In this process, industrial archaeology methods were used, based on the archival research. Historical documents were obtained from the Austro-Hungarian Empire period topologic project from the National State Mining

Archive. Documents of used technical equipment were obtained from the National Archive in Trnava.

The power plant for heavy oil burning in Piešťany was built in 1906 as one of the first of its kind in the former Austro-Hungarian Empire. Later, the plant only provided distribution and energy transformation till the 1990s. The original engine equipment was sold off and the main hall became empty [12].

After conversion, the building is now used as a technical science museum, which interactively educates about the energy and electricity sector. The machinery hall, which originally had six diesel engines and generators, is now a multifunctional room for exhibitions, scientific devices, and social events. Retained documents about the original state of the machinery hall allowed the exact appearance to be replicated through VR (**Figure 2**).

The materials, proportions, and details have been derived from preserved and functional historic diesel engines from the Technical Museum in Vienna through 3D scanning. Photogrammetric processes took 3 days. A 3D remodel of the historic 1906 engine was then created. Based on the interdisciplinary cooperation of STU experts and the analysis of historical documents, the historic appearance and hypothetical scene of the power plant machinery hall was hypothesized, presented via VR, and later fully animated. The movie was accompanied by sound taken from similar diesel engines recorded at the Technical Museum in Vienna (permission granted 2014). The sound was recorded using a camera Canon Eos 20D and Nikon D7000 with microphone (after permission was granted in 2014) and then optimized and purified via Adobe Premiere Pro and AGIsoft. This model serves as a 1:1 reference from which it was possible to analogically capture the proportions of the details (**Figure 3**) and drew them in new precise 3D model. Based on the archival research and the measurements in situ, we sought to find out whether the initial building was built according to plan in 1906. The next research identified all periods of the building's construction additions and removals and various stages of the finished look (1920–1945). For this case study, it was decided to visualize the first and oldest period from 1906 [12].

Figure 1.
Picture of the virtual machinery hall with machine equipment—at the first stage of the power plant in 1906 and the machinery hall in 2014 (3D model: O. Virág, M. Ganobjak, V. Hain; photo: P. Safko, 2014).

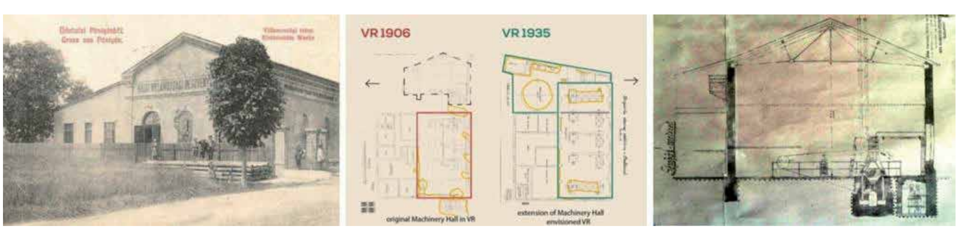

Figure 2.
Typological power plant and archival documents of the building, changes from the National Archive in Trnava from 1906 to 1938 (photo: V. Hain, M. Ganobjak, 2010).

3.2 VR 3D model

The digital 3D model of the building was created in accordance with the current measurements and compared with historical plans and construction phases as those were identified. Some standard components of the models (Industry Props Pack, Handyman Tool Pack) are from UE marketplace and Turbosquid (screws, watering can), and graphic works have been carried with texturing, UV mapping (UV layout), animation, and programming (Textured: Quixel NDO, DDO, Substance Painter and Designer).

The final application runs via the Unreal Engine (**Figure 4**). Initially the scene was tested with Oculus Rift, which had delays in the synchronization of head movements and caused dizziness of VR users. Finally the new more developed version is compatible with HTC Vive as well [12].

At this point, a user can see an atmosphere of characteristic historical design of space in the original, photo-realistic quality, along with animations and sounds in real time. The 3D model and VR objects were prepared in Unreal Engine 4, which provides photo-realistic images with high-quality textures and lighting. Outcomes are suitable for all these chosen devices: Oculus Rift, HTC Vive, Cyberith, etc. [13].

The VR scene for the old power plant created in 1906 (**Figure 4**) is designed for the visual communication of technical information, but it also ties in with the

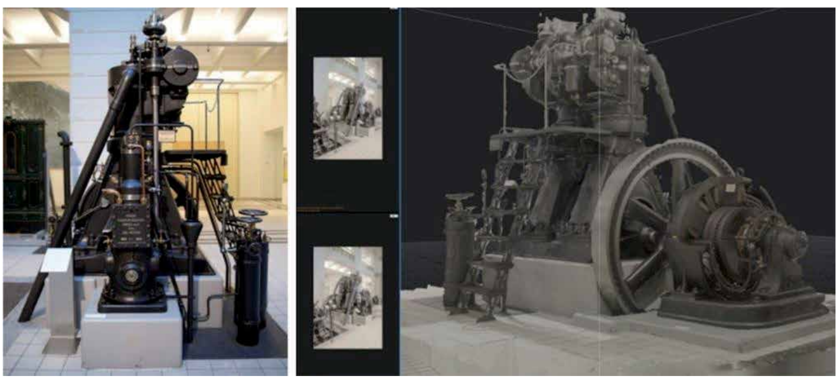

Figure 3.
Historical diesel engine from the Technical Museum in Vienna and photogrammetry via software RealityCapture and AGISoft (photo and 3D model: O. Virág, 2016).

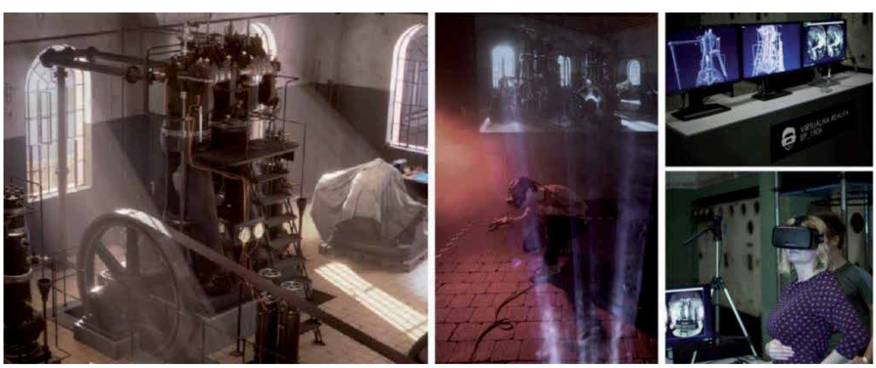

Figure 4.
Final VR 3D model of the virtual presentation were presented by VR headset Oculus Rift in the Power Plant Piešťany, where it was possible to compare the current and historical status on-site—an overlay of physical and virtual reality (photo: O. Virág, Ľ. Dait, M. Ganobjak, 2016).

diversity of the educational and multisensory exhibition, which is more universal (e.g., for people with disabilities). The target audience represents all the visitors to the hands-on science center EP (Elektrárňa Piešťany—Power Plant Piešťany), who can be entertained but also educated by an exhibition created in this way. The project target group consists of professionals and the general public. Primary school pupils can gain additional educational support from the exhibition. Animators, tutors, lecturers, heritage methodologists, curators, artists, and culture administrators can present new findings from the interactive history in practice, in addition to mediating facts from the world of science and technology history.

The created VR 3D model of the machinery hall seeks to eliminate the extreme situations of negative emotions of the space; it is "phobia-free." VR respects the senses and aims to eliminate negative emotions, thereby becoming universally appropriate. VR evokes feelings from this environment supplemented by authentic sounds of diesel engines that invoke an industrial atmosphere.

3.3 User tracking and data processing

The virtual machinery hall was tested at the European Researchers' Night in Bratislava, where it was explored by tracked visitors. The mentioned motivation, inducing natural behavior, was taking photos of the old power plant machinery. Supportive reward system with the impact on the real was publishing of their photos and motions on the second screen. Additionally, the user photographing was marking the most attractive exhibition places and motives. After the visit, users were asked to fulfill short questionnaires about the exhibition's quality and feelings in VR.

Users' positions and gazes were tracked in VR, every 0.3 s, and were collected with photographed views to the large point cloud as a raw data to work with on the further research. Users' positions were then extracted from the point cloud and noted via planar heatmap image by the contrast trace. The more time users spent on the specific spot, the more contrast the spot became.

This extraction enabled to visualize the attractiveness of certain places and process it by machine learning methods to create prototype of analytical tool for evaluation of new designed exhibitions (**Figure 5**). The created prototype of the analytical tool is a model based on the artificial neural network (ANN) trained by supervised learning. The supervised learning is teaching the network by the pair of related input and output samples [14].

Based on that, the planar heatmap with user's movements were resized to 40 × 66 pixels and sampled in 0.6 m—human module. After sampling the heatmap, every sample had 4 pixels. In the same grid of 40 × 66 positions, the 3D model of exhibition was analyzed by the isovist tool. The isovist is used for quantification of spatial openness by measuring the distances of the surrounding objects from the certain positions.

In our case, 24 distances of the objects from every position in the grid were measured. Every 24 distances were counted together, quantifying the openness of the space in every position in the grid. This measured openness of the space in the created planar heatmap, which was equally sampled into 4-pixel samples. Together with measures, the measured objects were categorized via importance in the exhibition. Objects were categorized into three groups, with different importance: (1) walls and windows, (2) secondary equipment of the hall, and (3) the main machinery of the hall. Every measure had then information about importance of the measured object, visible from certain point.

To achieve the heatmap of the exhibition importance, measures of the distances were multiplied by its importance. This way, the new heatmap of the exhibition

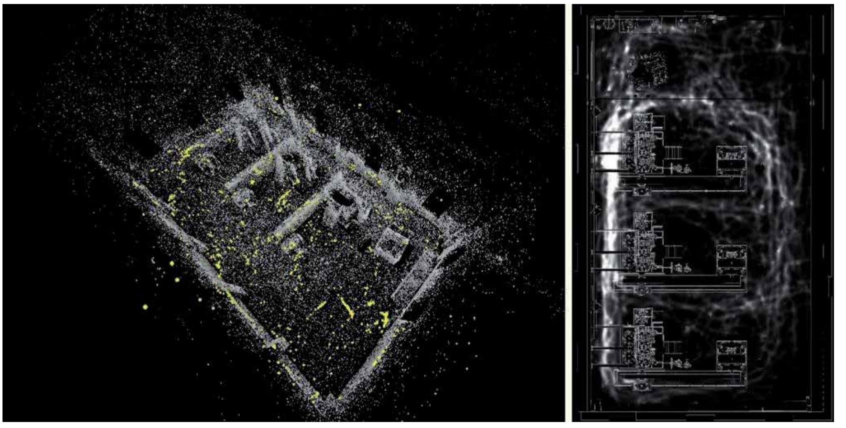

Figure 5.
Users' tracking data: left, point cloud of all users' view locations and positions; yellow points are photographed motives; right, map of all users' movements in plan view (R. Hajtmanek, 2019).

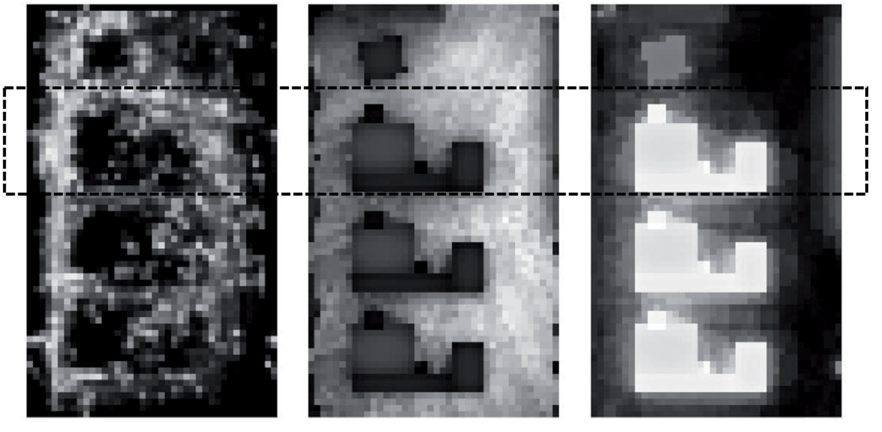

Figure 6.
Users' tracking data: left, downsampled users' movements map to 40 × 66 pixels resolution; middle, heatmap of spatial openness in the same resolution; right, heatmap of the exhibition importance. ANN was trained on the area, outside of the dashed frame. A testing set of samples was the part inside this frame (R. Hajtmanek, 2019).

importance was created and was also sampled to 4-pixel samples. Before training the neural network, every position in the grid had three samples: one sample of user's behavior and two samples of spatial parameters of the exhibition—its openness and importance. In the machine learning experiments, it is usual to divide samples to training and testing set. The training set is 80% of samples, and it is for supervised learning of the ANN. Remaining 20% of the samples is used for the testing the ANN. The splitting of the samples on training and testing set is visible on **Figure 6**.

Measurements of the space and sampling were made in Grasshopper, procedural modeling plug-in for Rhinoceros 6. ANN was created within this plug-in with Owl, ANN plug-in by Zwierzycki [15]. Supervised learning is based on related inputs and outputs. In this case, the inputs were the samples of importance (4 pixels) and openness (4 pixels), together as eight inputs. The outputs were the samples created from the heatmap of the user behavior, the four outputs. ANN had a structure of 8 neurons in the first input layer, 32 neurons in the three hidden layers, and, last, 4 neurons in the output layer.

4. Testing

This detailed 3D model was so interesting that Západoslovenská energetika, a.s. in cooperation with the Center for Environmental and Ethical Education "Živica" and iPARTNER followed up on this project and created an interactive application on electricity and energy for primary schools (**Figure 7**). The result of their cooperation with the team from FA STU is an interactive application based on VR game, through which pupils solve tasks related to the subjects of physics, chemistry, but especially electric energy. They informally educate themselves and can virtually visit the Piešťany Power Station in 1906 via the VR application.

This application has already been successfully tested at the Pavol Horov Primary School in Devínská Nová Ves—Bratislava in the last school year. It was tested by pupils from 12 to 15 years through the VR set and mobile phones. According to responses, there was a great interest of pupils in this form of education. Educators who have not had experience with the VR so far have shown interest in involving similar innovations in the education process in the future.

Experts on industrial heritage agree that the importance of presenting virtualized models of extinct historical objects is in several aspects:

- Reminder of local history and presentation of the site to the public.
- Initiating a public/professional debate.
- Reinterpreting the meaning for the present and the future.
- Effective (faster and clearer) understanding of the extinct historical object (VR, AR, 3D printing, holographic model).
- Effective nonformal learning.

Short-term use for the presentation of cultural monuments seems to be an appropriate and efficient use of the VR, which can personally approach a defunct

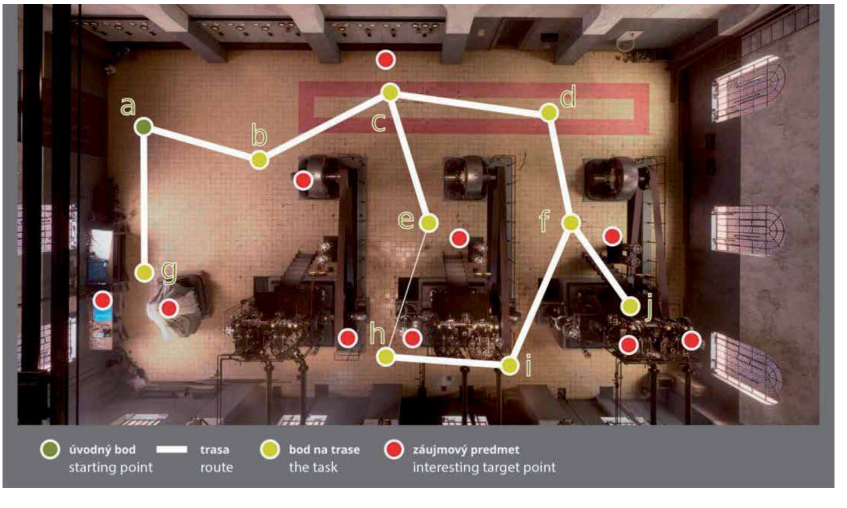

Figure 7.
Plan of interactive game with 10 tasks for students (authors: FA STU, Živica, ZSE, a.s., iPARTNER s.r.o., CRATE, 2017).

Figure 8.
VR application testing at the Researchers' Night 2019 in Bratislava and testing by students of the University of the Third Age of the Faculty of Architecture in Bratislava (photo: V. Hain).

building or site. The disadvantage is the high-input economic demands on the hardware and software equipment of the presentation, the technology (operating and explaining), and the low availability of the virtual reality headset, which each visitor uses only at the time.

The presentation in animated virtual reality with the possibility of synchronized movement in space is interactive and creates a subjective experience. It uses an audiovisual design, and in the original old power plant hall, it is sensually complemented by the historically present smell of black oil (unrefined diesel). This affects the imagination of the observer and allows his better immersion, the so-called "deep-rooted," and the potential for long-term information storage. At the same time, the presentation of the premises through the VR is a more interesting form for a wider audience of different ages and for people with some forms of disability.

The VR is able to appeal to an age-wide and professional audience, thus ensuring the transmission of the legacy of the non-preserved cultural values of the buildings of the past. Virtual reality has proven to be a suitable tool for commemorating the extinct heritage and reinterpreting its significance for the present (**Figure 8**).

5. Results

5.1 Education and experience

The created VR 3D model for the old power plant is adapted for the visual communication of technical information and aims to diversify educational and multisensory exhibitions. The target audience represents all the visitors to the hands-on science center EP (Elektrárňa Piešťany—Power Plant Piešťany), who can be entertained but also educated by an exhibition created in this way.

Such a presentation is suitable for people with various disabilities—the possibility of virtual movement without physical movement for people in wheelchairs; for the deaf, a visual scene; for the visually impaired, intensive contrast of colors and brightness; and for the blind, a sound experience.

Animators, tutors, and presenters can showcase new findings from history interactively, as well as science and technology facts and figures. The project has a research and innovation character: arising from interactive applications with educational content [16]. The project output is aimed to be an application in the popular scientific center at the power plant in Piešťany as a new permanent part of the exhibition.

The project has a reproducible character: it can be used to support educational activities in the electricity and energy sectors, other educational institutions, and schools. This will create conditions for project results to be shared across Slovakia, inspiring repeatability for other science and tech areas.

Raising awareness about industrial heritage can bring a better understanding of its meaning in terms of the diversity of cultural heritage [17]. VR provides a quick educational effect compared to laborious videos or models. Visitors of VR spent around 2 min on average there. The opportunity to synchronize movement, sound, sensations, and walking and looking in VR delivered a unique personalized experience and memories.

The VR 3D model in the exhibition enables the creation of new exhibition attractions with virtually unlimited dimensions, the overlap of the virtual and real world, while also saving physical space in the exhibition. This is enriching exposure. The overlap of virtual and real worlds and the related synchronization of movements of the body and head enhance the immersive (recognition) personal experience [18].

The multisensory VR experience at the power plant Piešťany involves multiple senses (sight, hearing, smell, touch), applying the principles of universal design (multisensory perception, easy operation, etc.), allowing versatility to exhibit and usability by various visitors. VR has eliminated extreme negative emotions related with space—fear of heights, too much closeness or openness—and will not shock with fast-moving animated elements, i.e., it is "space-related phobia-free." During the testing any serious health impacts of using VR or subsequent phobias have not been detected.

5.2 Questionnaires

During the European Researchers' Night, users fulfilled together 59 questionnaires evidencing presentation popularity, after the visit of VR. Most of the respondents would visit the old power plant for the education by VR. Only smaller part of the visitors had not experienced VR yet. Seventy-five percent felt comfortable in VR, but there were also several visitors, who feel little headaches. However, most had no problem with orientation in the virtual space, and they would stay longer than 10 minutes. Based on that data, it is possible to consider this model of education as not harmful, safe, and meaningful. Answers expressed in percentages are shown in **Figure 9**.

5.3 Tracking

During the visit of the virtual machinery hall, the positions of visitors and their views were tracked. Together, the data from 165 visitors were gathered. The tracking showed that visitors saw just one third of the space (33.91%) on average. There was also a presumption that visitors would mostly take photos of machines in the middle of the hall (as the main part of the exhibition), but only 28.82% of photos captured the machinery.

5.4 ANN predictions

In the subsequent research, tracked data about users' movement trained the AAN to predict visitors in the space. Such a prediction could be useful for evaluating the suitability of similar exhibition designs. In the training phase, AAN was trained on 80% of the samples. After that it was tested on the remaining 20%. The AAN created the new heat maps of predicted users' movement, from inputted spatial openness and importance. These predicted heatmaps were then compared to original users' movements' heatmap to analyze the ANN accuracy. The compared heat maps were blurred and colored to distinctly display the differences and equalities (**Figures 10** and **11**).

Comparing the maps graphically, the ANN achieved sufficient outcomes with the trained set, because those areas are rather similar. Outcomes of testing set are also similar to each other but with lesser accuracy. Nevertheless, the ANN learned some patterns, as it recognized the movements around machines and the most attractive places behind them. With that prototype, it is now possible to evaluate similar exhibition spaces and directly design them without any other users' feedback.

Tracking the users' movements and pairing it with measured parameters of the virtual space proved as valid source of information for developing the machine learning-based evaluation tool. Further research in this direction should include even more spatial properties as illumination and materiality to offer more data to the ANN. With bigger data, precision of ANN is increased to recognize the patterns. Gathered user data from the exhibition enable to investigate this field from different perspectives as pairing the movements with their motivations (photographed views and users' gaze properties), to teach ANN to predict the user viewing and orientation.

Further research could be also transferred to real space. Although the VR offered the ideal experimental control and sterile, laboratory environment, with machine vision technology, it is possible to track people in the real space, enabling to pair their behavior with the spatial properties. These spatial data could be achieved from its virtual representation or to be physically measured. That way, the spaces would not have only exact, measurable parameters but also statistical value of human response to them.

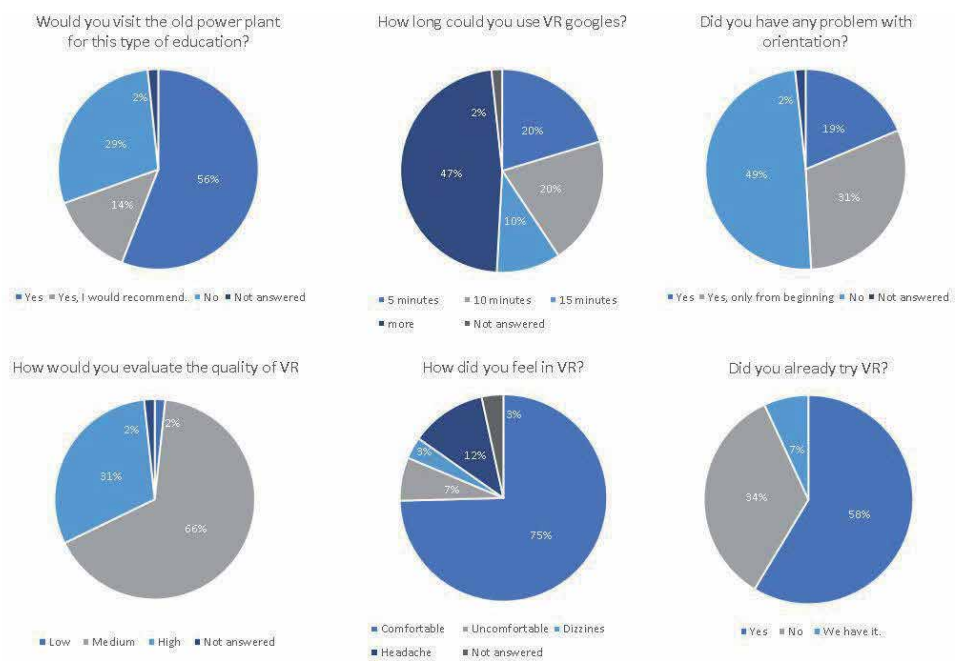

Figure 9.
Answers from the questionnaire, fulfilled after the visits (V. Hain, R. Hajtmanek, 2019).

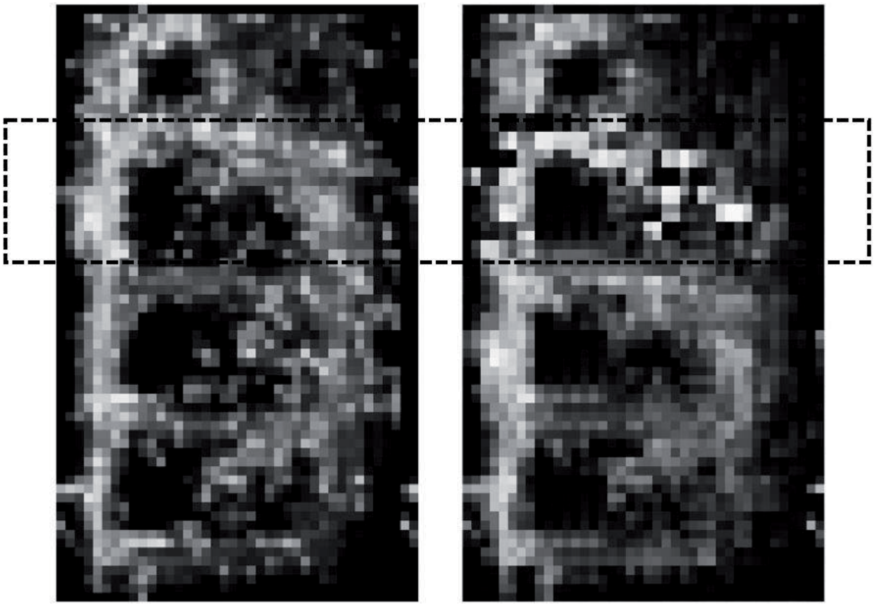

Figure 10.
Comparison of the original and predicted users' movements' heat maps. Left, original downsampled heatmap; right, predicted heatmap by ANN. Tested area is inside the dashed border (R. Hajtmanek, 2019).

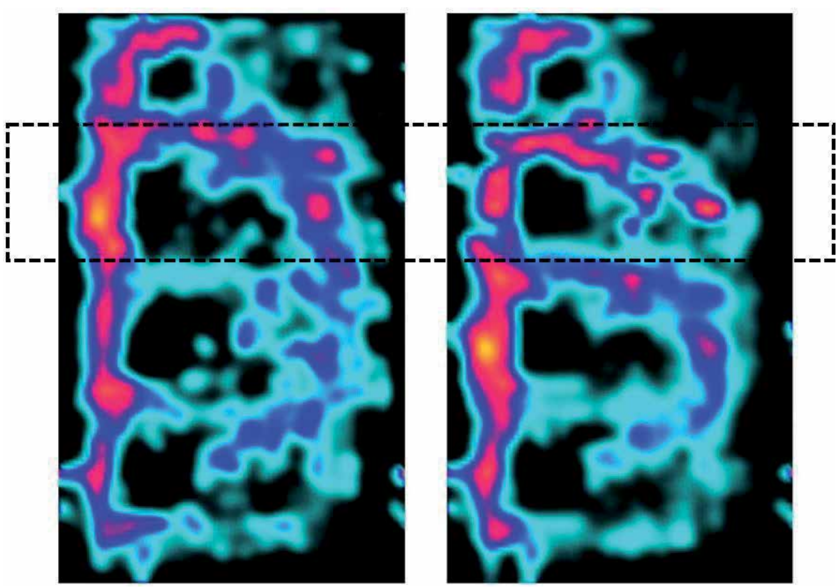

Figure 11.
Contrasted and colored heatmaps (R. Hajtmanek, 2019).

6. Discussion

The research raises questions about VR's usefulness, relevance, controversy, and entertaining applications. Numerous psychologists also suggest that inappropriately applied VR may constitute a risk: being cut off from the real world and creating a brain fallacy by optical illusion is unnatural and in the long term risky. In this case study, VR as a practical tool enables the public to learn about bygone heritage.

Even with the numerous controversial VR uses, this example of VR could be considered meaningful and beneficial in practice [19].

The virtual visit of the industrial space teleports the viewer into a virtual scene where it is also still possible to look around in a traditional manner. Virtual reality allows the handicapped to perform virtual movements without physical effort to places/through places where it would otherwise be impossible to go.

In this case, Oculus was more useful than HTC Vive (depends on the mobility of physically impaired persons). The same virtual scene is perceptible from the perspective of a pedestrian. The perception of users and feeling of size could be changed (the visitor is like a giant, and the scene is only a scaled model, or vice versa).

The opportunity to experience a future, fictional world, to take a walk in the past (**Figure 12**), or virtually teleport to other points of interest is opened up through VR presentations. Visual perception is supported with realistic materials and textures. Experience in a VR scene installed in the original Machinery Hall is supported by the real in situ scent of heavy oil which is still possible to be smelled in the existing premises.

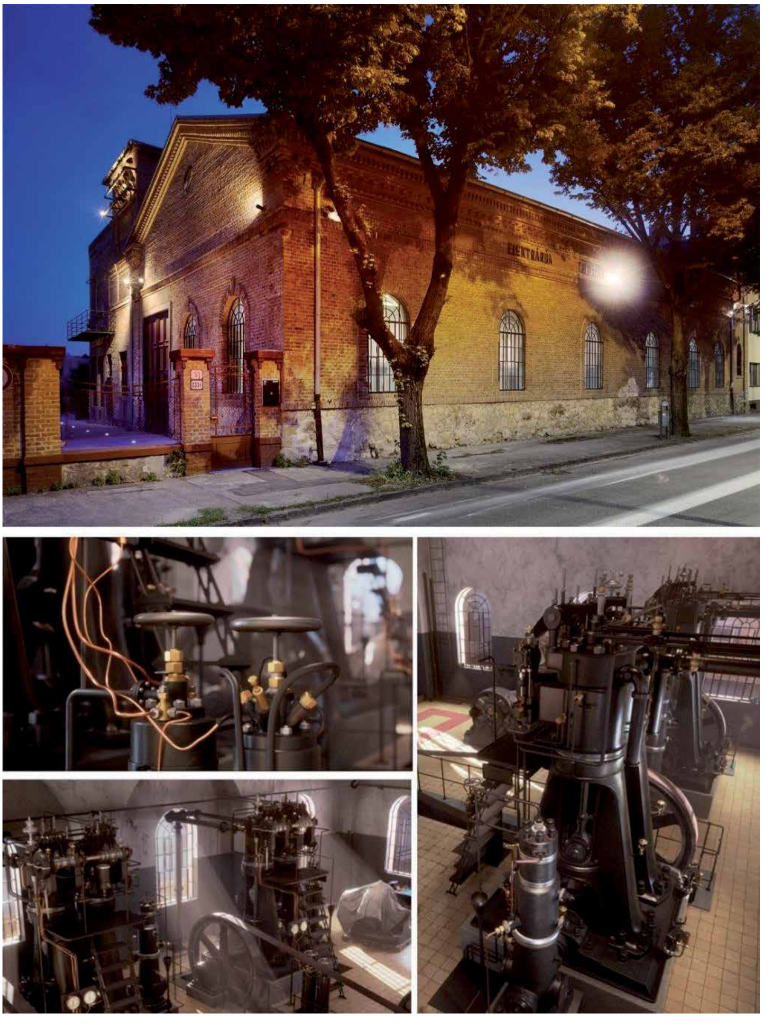

Figure 12.
The final results of reconstructed building with realistic virtual presentation—output of Unreal Engine 4 (Project of reconstruction of old power plant Piešťany: M. Ganobjak, V. Hain, M. Paško, Z. Zacharová, 2014; 3D Model—BAT engineering 2015, VR processing—Virág, 2016).

Virtual reality with synchronized movement enables from anywhere, even from outside Pieštany, a walk in the historic yet nonexisting interior of the Machinery Hall of 1906. Synchronized movement in virtual and physical reality (**Figure 12**) is compelling and confirms the meaningful use of virtual reality as a vehicle for presenting the defunct cultural (industrial) heritage against the backdrop of a direct comparison of the contemporary and the original state [20].

The absence of a virtual avatar body in the VR as reported by visitors was a strange experience with feelings of disorientation and confusion, although it is disputable if the presence of an avatar body in VR would have avoided those feelings. Augmented reality, accompanied with the use of physical reality as an anchor for position and navigation, appears to be a further tool for effective education, with the brain effectively distinguishing the essence of a variety of information at a real place. Virtual reality has also shown in this case study to be useful for presentations at several events outside the industrial heritage site.

7. Conclusion

The competent management of cultural heritage requires thorough knowledge and evaluation of the subject causality—with a strong theoretical background and a target-oriented assessment perspective of the presentation and education level.

The case study through VR has reinterpreted the history of the cultural industrial heritage which was not possible to recover in physical reality and have brought it to a contemporary audience. Through this practical interactive tool, the general public can learn about lost heritage. Interactive virtual parts can be embedded in conventional channels and animations controlled by focusing on specific objects. A brief VR experience in machinery halls in an exhibition with a safe level of emotionality, and high immersion in a historical environment has a clear educational benefit about lost industrial heritage and appears an appropriate and meaningful use of VR.

User tracking and the whole principle of interdisciplinary cooperation is not only a synergistic element in a complex organized design process but also a key educational element in the protection of the local industrial heritage for involved participants.

However, each case of heritage management requires a specific and detailed study of the subject. Therefore, neither the criteria specified nor the flowchart presents absolute and conclusive results about the case studies. Therefore, the study aims to serve as an initial model for further studies on the application of virtual reality in the preservation and educational management.

Acknowledgements

This project has been supported with public funds provided by the Slovak Arts Council FPU 16-362-03415 and by the subsidy project Supportive Program for Young Researchers EPUVRSU 1304 and KEGA 038STU-4/2017 "From the laws of nature to technology by experience—a project of informal interactive learning of pupils and students encouraging interest in technical fields."

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Chapter 6

Designing Interactive and Immersive Multimodal Installations for People with Disability

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Abstract

We developed an end-to-end co-creative methodology for designing interactive and immersive multisensory virtual reality experiences with a particular focus on people with disability. Our method draws on what is called "design thinking" to provide a backbone to our approach. This embraces three stages, an empathic first stage, followed by an ideation phase, during which the thematic context is elaborated, and then an iterative exploration phase during which the initial concept is refined and the implementation is achieved. Furthermore, the "cognitive design" methodology developed by one of us led us to an approach incorporating all sensory modalities, not just the audio and visual modalities (that is, it includes odor, tactile, taste and proprioceptive stimuli), in order to deliver an experience that fully enhances the user's sense of embodiment, and also led us to place the user's experience at the heart of the installation. Users participate in the design process through co-design protocols. We showcase the application of this methodology in a detailed way for the construction of an interactive and immersive VR installation for people with disabilities.

Keywords: immersive interactive installations, disability, design thinking, participatory design, virtual reality

1. Introduction

The best way to find yourself is to lose yourself in the service of others (Gandhi)

For years, researchers, scientists, and artists have worked with similar aims: to create, innovate, and share knowledge across diverse fields [1]. Sometimes, these innovators are classified into one of two categories: either as finders or makers [2]. Both of these are equally creative. Finders focus on their energy and creativity on understanding phenomena to increase the stock of knowledge about these, making quicker decisions to establish or confirm facts, and thereby solving new or existing problems. Meanwhile, makers or creators bring forth their own ideas and conceptual knowledge, to create and design for others [3]. Both could be understood as oriented toward what Heidegger called *Dasein* [4], that is, *Being* understood in relationship with others while the self remains alone and aware of our mortality. Within such a framework, both finders and makers equitably care about how to make the world a better place for themselves and others. Aspects of this Heideggerian concept of "Being" were embraced later by Deleuze, who translated this in terms of creativity, and considered Being as *unlimited creativity where creation depends on the one creating* [5]. Design encompasses a set of methods and tools for carrying out such a program.

Design is an exploratory process [6] that often starts with abstract ideas that gradually grow into more definite specifications through iterative cycles that adjust the solution [7] to the desired application context. An ongoing cognitive process, designing is like thinking: it is an ubiquitous activity of human creation, regularly triggered through the problem-solving process [3]. Design embraces a crucial skill set for understanding and responding to the needs of others, especially in the constantly changing world in which we live. One way to approach design is called Design thinking [8]. Design thinking offers an efficient way for researchers, scientists, and artists to innovate productively for others in a context of rapid change [9]. It offers a frame for understanding how designers undertake human-centric problem-solving for creating objects, services, or systems, as well as offering a hands-on methodology [10].

Building upon participatory, human-centered action research, the design thinking process may be viewed as occurring over three distinct phases: (1) *empathy*, in which an empathic understanding of the needs to be addressed is obtained from users, (2) *ideation*, during which ideas are generated [11], and finally, (3) *experimentation*, where methods are developed and tested to implement the ideas. During each of these phases, designers engage in different cognitive activities including thinking, preparing, and assimilating new knowledge [12].

Design thinking as a practice has drawn attention across different fields including engineering [13], business science [10], and education [14]. The approach has also been used in disability studies and the development of human-computer interaction (HCI) for people with impairments [15]. Design thinking has been shown to offer a high degree of flexibility for these applications. Indeed, designing for people with impairments is challenging, as they often require a range of special adaptations using highly personalized equipment—one size does not fit all. Generally, teams working in this area must arrange for design assistance from appropriate experts, for example, with training in ergonomics or biomechanics, as well as people with disabilities themselves, in order to develop an understanding of the factors that affect the participation of people with disabilities [16]. To address these issues, universal design principles [17] have been adopted for designing both natural and urban spaces to ensure their accessibility and safety.

Interactive and immersive digital installations are a relatively recent artistic innovation [18]. The range of installations that have been developed is already large, however, and they are not always well reported in the literature, making it difficult to get a handle on the breadth and diversity of productions. Some general distinctions include primarily immersive audio installations [19, 20], immersive storytelling installations [21, 22], somatosensory and movement-based embodied installations [23, 24], and immersive digital culture installations [25–27]. With regard to issues of accessibility for these installations, however, the written record is meager, and what evidence there is suggests accessibility is an issue. Accessibility is defined in the dictionary as "the quality of being available when needed". However, even today, minority groups such as people with impairments, or the elderly, can find themselves excluded in many, even most, contexts. This exclusion is usually the result of a poorly organized environment and/or disabling interactions [16], that is, it is a result of the designers' lack of understanding of the dynamic interaction between environment and personal factors. In order to overcome this problem, designers must step out of conventional ideas, and learn to experience the world through their own vulnerability in empathic resonance with people with disabilities.

Designing for all goes beyond ensuring accessibility, it also requires that the installations explicitly include representations of disability, to motivate people with impairments to participate. Furthermore, people with impairments need to take part in the design process to be fully engaged [28]. Also, one of us developed a cognitive design protocol in earlier work [1] for developing assistive technologies for people with disabilities. Cognitive design draws upon knowledge of human cognition in order to design technologies with a broader basis of application. Hence, for example, Yaagoubi et al. [1] presented a tool to assist people with visual deficits to orient themselves in space, drawing on the hierarchical organization of spatial information in our cognitive representations of geographical space. The approach, which we called cognitive design, consists of matching data organization methods and technical requirements to cognitive principles, and is quite general. In principle, it could also be applied to installation design. We drew on these ideas to situate the design process for our interactive and immersive installation development work, as we shall detail below.

A quick note about terminology: we use the expressions "people with impairments" and "people with disabilities" interchangeably, although in fact there is a difference between the two. Impairments are understood to be the functional limitations associated with persons, while disabilities are understood to be the result of a maladapted environment, which renders impairments disabling [16].

In this chapter, we present our end-to-end co-creative design methodology for the development of interactive and immersive multisensory virtual reality experiences, with a particular focus on designing installations for people with disability. We also showcase the application of this methodology in a detailed way via the "رحلة - réhla (Odyssey)" project.

2. The process of co-designing an immersive and interactive installation

To design a user-centered, immersive, and interactive installation that addresses the needs and interests of people with impairments, we adopted an end-to-end co-creative design methodology, inspired by the design thinking process. The proposed methodology is composed of three phases: (1) empathy, (2) ideation, and (3) experimentation. Each of these phases is detailed below.

2.1 Empathy

The idea of empathy was introduced by Lipps in 1867 [29], and originally referred to the process of projecting oneself into a perceived object or person so that a sense of identification occurs. Later, however, the term has been used in a variety of ways. Bachrach [30] proposed a general definition as follows, although not everyone agrees: "the concept of empathy... refers to the ability of one person to experientially 'know' what another is experiencing at any given moment, from the latter's frame of reference and through the latter's eyes." This definition covers the essential idea for this discussion, the idea of "feeling oneself into" [29] another person's experience of the world. To achieve this, designers must set aside their own knowledge and needs, and focus on first understanding how others interact with the environment. This goes beyond, therefore, the idea of "needs assessment" that typically forms the first stage of an engineering project [31]. The success of this first stage of the design thinking process depends on integrating all the relevant elements in the problem-solving process.

In the context of designing for people with disabilities, additional elements also need to be taken into consideration to ensure that the solution serves people of all ages, personal abilities, pathologies, and sizes [32]. Designers are called upon to apply universal design principles [17] to create buildings, products, services, or environments that are accessible for all people. Virtual as well as physical environments require design assistance to develop a deeper understanding of user interactions, as well as changes required to both policies and procedures [33]. Ensuring access to virtual environments goes beyond making them accessible [34]. Indeed, immersive and interactive installations need to reflect users' experiences, as well as their interests and personas. The concepts incorporated into the design need to be based on an explicit understanding of people with disabilities, and in particular address their needs in terms of risk and safety management [33]. In a more paradoxical way, it is about supporting both designer and user visions to the best advantage of all. To ensure this, designers must involve users in the complete process. Perceiving another's vision implies putting oneself into someone else's place, allowing oneself to be vulnerable while gathering, assimilating, and processing the experience.

Participatory design (PD) is one of many cooperative design approaches that have been successfully applied to the development of human-computer interaction environments (HCI) for people with impairments [15] . The very essence of this approach is about engaging neglected users in the design process to inspire more systematic changes in social organization [35], while at the same time empowering participants [36]. Our proposed methodology combines both design thinking and participatory design in each of its phases. The roles of both the users and the designers are redefined, to create fairness and a proportionate benefit for both [37].

رحلة - "réhla" is an Arab word for travel or journey. The choice of this name was not an arbitrary one. Indeed, to implement "رحلة - réhla (Odyssey)," the design team engaged in a lengthy, sometimes chaotic yet exciting journey. This began when we first investigated the problem of designing immersive installations for people with impairments. A personal, yet shared interest among members of the research team, this was fueled in part by our realization of the extent to which people with disabilities face risk on a daily basis [28]. For some, it was also the continuation of research that had been carried out over a number of years, whereas for others, it was about ethical principles and generating new forms of societal value. Furthermore, involving the participants in the design process showed us that rendering these installations accessible for people with disabilities involved a sharing of visions.

2.1.1 The first design concept: Vertigo

To the best of our knowledge, very little research has been applied directly to the problem of designing immersive and interactive installations for people with disabilities, due in part to the complexity of making these accessible yet safe for all. In early 2017, we developed the concept of *Vertigo*. This was to be an installation that placed participants into uncommon situations such as floating and defying gravity. It was a continuation of earlier work on developing embodied experiences in virtual environments, that is, experiences that would enhance consciousness of body states. Participants would be placed on, for example, a robot-supported platform over a virtual, bird's eye display of the city of Quebec. This would provide a multisensory experience that offered for some participants an adrenalin-loaded moment, while others might experience calm floating. Nonetheless, we were aware that such an innovative and ambitious concept could not be achieved without involving participants in its design. To overcome our own lack of knowledge about what elements should be incorporated, we set out to conduct a qualitative study to examine the perception of risk and the decision-making process involved in accommodating such risk among people with disabilities [28]. The results of this qualitative study are briefly summarized in the subsection below.

2.1.2 The qualitative study

In the summer of 2017, we began recruiting and interviewing a broad range of people with disabilities. In semi-structured interviews, participants aged between 30 and 59 years answered questions about: (a) Safety and risk management; (b) Loss of control; and (c) Experiences of Vertigo. All sessions were audio recorded and then transcribed verbatim, analyzed, and coded. The results of this qualitative study [28] demonstrated that people with disabilities experience risk on a daily basis and deal with it in different ways depending on their functional limitations, personal factors, past experience, and other factors. Regardless of their particular functional limitations, they all found creative ways to manage the risk of injury in order to carry out their lives. In fact, the study showed that managing risk is composed of four stages [28]:

- assessment phase;
- adoption of a structured decision-making strategy;
- adapting decisions actually taken due to unexpected events; and
- managing the sometimes intense feelings elicited by challenges.

The identification of the four stages of the risk management process provided the basis for how we planned to organize the installations. Moreover, almost all the interviewed participants agreed that the *Vertigo* concept did not represent a substantive change from their high risk daily routine and therefore expressed little interest in experiencing it. Based on these findings, it became obvious that in order to engage these participants, we needed to offer them something more adapted to their actual experience of the world. Instead of seeking out experiences of risk, they were drawn to experiences of calm and safety, experiences that promoted relaxation and well-being.

2.2 Ideation

The qualitative research study provided us with a strong basis from which we could explore such a concept. People with disabilities clearly asked for a safe relaxing space in which environmental and emotional barriers had been reduced. They also pointed out the importance of being able to explore usually inaccessible locations such as natural environments. Raising awareness among the general public about accessibility issues was also important for them [28].

Given all these facts, we determined to rethink our concept. We decided to take some time away from the creation process, to step back and reflect on the results of the qualitative study and on the participants' real needs. After a hiatus of about 2 months, the main designer A. Arfaoui proposed the رحلة- réhla (Odyssey) installation concept.

Fully aware of the importance of involving people with impairments in the design process, we set out to invite the same participants that we had first met as part of the qualitative research [28] to provide feedback on the new concept. We decided to trace four main aspects in relation to the concept and further discuss these with the group:

- revisiting the definition of accessibility;
- how to create an experience of relaxation and well-being;
- how to include in appropriate and effective ways issues of safety; and
- how to use the installation to raise public awareness concerning accessibility to natural environments.

2.2.1 Focus group

As we started planning the focus group, it was necessary to carefully think about sampling (who should be invited to participate) as well as how to achieve full participation and equal access for people with disabilities. For this, we formed two groups: (1) participants with a broad range of impairments and (2) researchers and experts. For the first group, we invited back many of the same group that had already participated in the qualitative research, hoping to ensure continuity in the co-creative process. The second group included researchers working in targeted research areas related to disability studies, accessibility, and virtual environments. During the co-creation session (focus group), both groups were equally active and played significant roles in conducting the session. The session was divided into two parts: in the first part, the concept of the proposed installation was presented and critiqued, while in the second part, we discussed modes of evaluation and looked for improvements.

2.2.2 The second design concept: رحلة - réhla (Odyssey)

2.2.2.1 Presenting the concept for the installation

The installation as conceived, proposed a journey to one of two natural environments within which participants were invited to relax. The installation was inspired by the often moving testimonies gathered from the qualitative study participants, as well as childhood experiences of the main designer, A. Arfaoui, who chose to introduce the participants to the Sidi Bou Said beach in northern Tunisia, where she grew up. For the second environment, a fictional site inspired by Quebec's Nordic forest was chosen. Both destinations are usually inaccessible for people with disabilities. Moreover, they may also, paradoxically, create experiences which can be simultaneously happy and sad. This is the result of the vulnerability that may arise when we are relaxed, or when we are alone or surrounded by silence. Participants in the qualitative study remarked on this aspect of experiences of relaxation.

In the context of the رحلة - réhla (Odyssey) installation, participants would be invited into a dedicated white-chamber, would don a 3D virtual reality helmet, and then let themselves relax while interacting with a multisensory environment, including sight, hearing, touch, and smell. Each of the different elements included should contribute to transporting participants to either site, evoking the designer's vision, while finding ways to make the experience their own. Furthermore, the installation should accommodate as many people as possible, regardless of whether they live with a disability or not. Once installed in the environment, the participant would also be given the opportunity to modify the experience, varying colors, and sounds, in order to further personalize the experience, and enhance enjoyment.

To present the concept, a 6-minute video recording was prepared and shown to the Focus group participants, in which reference was made to both the Odyssey concept and the two natural sites. A PowerPoint presentation detailed the different stages of the proposed installation and its main features. Since a visually impaired participant was present, we created a model to represent the chamber hosting the installation and showcased certain elements used in the environment. The model provided, in addition, tangible benefits to other members of the co-creation session. Indeed, through touch and feel, our blind participant was able to understand the proposed environment, and the model provided a visual configuration to the sighted participants as well. We also presented noise and olfactory samples, which contributed to increasing the participants' engagement and underlined the diversity of the proposed installation stimuli.

2.2.2.2 Enriching the concept

Once we finished presenting the concept, the participants were ready to give us their perspectives on what they thought about the proposed installation. Some were excited and looked forward to being a part of the planning, implementation, and experimentation, while others were skeptical and began identifying problems or making suggestions for improvements, particularly with respect to safety issues, viewed as essential if relaxation was to be achieved.

The first point raised was in relation to the accessibility issue. Indeed, participants were eager to go back and redefine it, to help us understand what we would need in order to create an accessible experience for all. It was quickly realized that our definition of accessibility, which focused on the physical and environmental aspects of the installation, did not fully reflect the understanding of people with disability. Indeed, from the perspective of the members of our group 1, one cannot talk about accessibility without also addressing issues of safety. This is a direct result of the fact that people with disability experience high degrees of risk in everything they undertake, as revealed by our qualitative study. Hence, a definition of accessibility that does not acknowledge issues of safety makes no sense. Furthermore, for environments to be accessible to people with disability, they must incorporate a representation of disability within the environment. Without such a representation, they always feel excluded. Examples of what is meant by this are the presence of accessible ramps or ways, podo-tactile tiles, or other indications that accessibility issues have been addressed when the environment was developed.

In the proposed installation concept, we took into consideration these concerns, offering participants a range of choices, and included them in the decision-making process for developing the installation. Nonetheless, participants still found both environments to be lacking explicit disability representation. It was suggested that we add more indications of accessibility such as wheelchair ramps or a wooden path to support their access to both 3D environments.

They also pointed out that there are other barriers than purely physical ones that need to be addressed, including social attitudes such as prejudice. Participants from both groups agreed that dealing with risk remained personal, and varied from one person to another. The memories of past experiences strongly influenced the assessment of risk. To address this issue, it was suggested that we provide the choice to stay or leave the experience at any moment, thereby ensuring their control over events as they unfolded. They also wanted a more active role during the experience. They viewed the personalization of colors and sounds as useful, but insufficient. They wanted greater control over the choice of scene elements, over their position within the white-chamber, and over the duration of the experience. Based on these remarks, we decided to redesign the white-chamber and its elements to be easily dismantled and replaced in accordance with the choices made by the participant. All these issues led us to become more fully aware of how to accommodate the needs of people with impairments, and underlined the importance of having included them in the design process.

2.3 Experimentation: the رحلة - réhla (Odyssey) installation

Even though the installation concept was by this time both highly specific and validated by people with disability, we still needed to gather comments and suggestions during the experimentation and implementation phase. To implement رحلة - réhla (Odyssey), meetings took place on a weekly basis with both the researchers and expert team members, and one or two people with disabilities, to work out the development and construction timelines. We examined closely every detail and selected appropriate elements to meet the requirements. With the development of the virtual environment being more demanding, this work was begun months before engaging in the physical construction of the white-room, which was further constrained by the fact that we would have access to the physical space only for a limited period of time.

2.3.1 Prototyping the virtual environment

Creating an immersive and interactive installation involves designing 3D environments to which users would be given access via a virtual reality interface (3D helmet). For the رحلة - réhla (Odyssey) installation, initial ideas were developed using sketches as well as a physical mock-up of both places. A specialist in 3D virtual design was hired (J. Proulx-Guimond). The beach site (**Figures 1** and **2**) was created using maps of the Sidi Bou Said beach, and also drawing on A. Arfaoui's memories, concerning, for example, the color of the water, of the sand, the birds present or even rare regional plant species. These were supplemented by recent photos taken *in situ*. Naturally, accessibility found its way into the design through the creation of a wooden walkway and platform (**Figure 3**) among other elements. Furthermore, access was offered to the site at two different times of the day (morning and late evening). A beach offers a different kind of relaxation during the evening (**Figure 4**) than during the day. To these were, of course added, sounds of the waves and birds, as detailed elsewhere (**Figure 5**).

For the Nordic forest, we drew our inspiration from an aerial photograph of a cabin on the edge of a lake, but modified the scene to create landscape elements to enrich the experience. These included a ravine with a stream, a waterfall, and mountains as well as boreal forest. The idea was to offer a relaxing yet inaccessible environment that people with impairments cannot easily visit. For this, a cabin was placed near the top of a cliff (**Figures 6** and **7**). A wooden walkway and platform, similar to that developed for the beach site, were also introduced. Again, an evening

Figure 1.
The Sidi Bou Said beach as depicted virtually, looking west.

Figure 2.
The virtual model of the Sidi Bou Said beach, looking east.

Figure 3.
The wooden walkway and platform within the shade of its parasol. The walkway extends from the road, across several hundred meters to this location near the waterline.

Figure 4.
The virtual model of the Sidi Bou Said beach at night, looking west.

(sunset) time of day was also modeled (**Figures 8** and **9**). The sound of the waterfall, the wind, and a variety of bird songs were also provided. At any time of the day, the Nordic forest inspires absolute relaxation and well-being.

The two virtual sites took 5 months to develop, half time. It was decided to slow the development by paying the developer to work half time, since we were still working out diverse design issues. We needed breathing room to fine-tune the design specs as the work proceeded.

Once the 3D visual environments had been developed, these were supplemented with appropriate sounds, smells, and tactile elements. A partnership with an olfactory Tunisian company, *La maison des senteurs*, was organized, which provided appropriate scents for both environments. These scents were presented to the Focus

Figure 5.
The virtual model of the Sidi Bou Said beach at night, looking east.

Figure 6.
The Nordic forest site, showing the cabin, rock faces, waterfall, walkway and wooden platform.

Figure 7.
The view from the wooden platform, located in front of the cabin, during the day.

Figure 8.
A view of the walkway and cabin at sunset.

Group, in order to validate their choice. The visual experience was also supplemented with sounds. For the beach scene, we included the sounds of the waves and children's voices, as well as the cries of gulls. For the forest scene, bird songs were introduced, the sound of the waterfall, and the sound of the wind. In addition, music was offered for both experiences. Given the fact that music choice tends to be highly personal, we consulted a music expert to help with this aspect (Jocelyne Kiss). All sounds and music were offered to participants as choices that could be added or suppressed (and volume adjusted) as they wished.

رحلة - réhla (Odyssey) offered a multisensory immersive and interactive experience based upon a wide range of different stimuli. Once the overall experience had been designed, we focused attention on the interactive elements. To do so, we

Figure 9.
The view from the platform at sunset.

Figure 10.
The cabin-like structure inside the white-room, shown with a person lying down in the lawn chair and wearing the 3D helmet.

Figure 11.
The flower box, with forest plants and soil.

Figure 12.
The sandbox, which, in addition to sand, also contained shells, pebbles and algae.

Figure 13.
The scent diffuser.

co-designed with our participants a white-chamber where participants could perceive and engage with the experience in a safe manner. Obviously, the white-chamber had to include assistive technology accommodations, as well as create a suitably relaxing atmosphere for people with impairments. Having an expert architect among our team members (Morales) facilitated our design efforts in this regard. We first decided to build a one room chamber simulating the cabin (**Figure 10**), inside of which was placed a comfortable, inclinable lawn chair so that participants could lie down and truly relax. In addition, a sandbox and a flower box were offered to provide participants with tactile textures for each virtual site (**Figures 11** and **12**). To dispense scents and thereby generate a fragrant environment, we used a scent diffuser to provide the participant with a distinctive olfactive journey for each site (**Figure 13**). Participants were given the option to remove any of these elements, or to use their wheelchair instead of the lawn chair if they wished.

The white-room itself was constructed over 2 weeks in the final period before launching the installation.

3. Experiencing the رحلة - réhla (Odyssey) installation

To test the complete installation, each member of the design team went through it first to generate feedback before inviting participants with disabilities to try it. By the end of this internal testing phase, we developed a clearer understanding of how invited participants might behave, think, and feel when interacting with the installation. This, however, was insufficient to determine whether the installation truly succeeded in creating a relaxing, safe, and accessible installation while at the same time raising public awareness of issues of disability and accessibility.

Wearing a 3D helmet has been known to cause eye fatigue, which was one concern. We were also still unsure how much time to allocate to the experience as a whole. Before opening the installation open to the public at large, we invited one participant with disability (whom we will call "P" to keep his or her identity secret) who was present from the very beginning of the project, to inaugurate the installation and help us make final adjustments. "P" was asked to undergo the experience for almost an hour. Upon arrival, and for 15 minutes, "P" was welcomed by A. Arfaoui, who provided explanatory context, presented the installation, and explained its features. Thereafter, "P" was asked to sign a document of consent before transferring to the lawn chair in the white-room. For the next 30 minutes, "P" was able to explore and mostly to relax, wearing the 3D helmet, managing to navigate between the different locations while interacting with the multisensory installation. The 1 hour session ended with a discussion during which answers were sought to a series of questions concerning: (1) accessibility, (2) relaxation and well-being, (3) safety, and (4) raising public awareness.

According to P's experience of رحلة - réhla (Odyssey), the installation exceeded expectations. "P" had been unaware of the power of a virtual multisensory environment and had been skeptical that the installation would provide both an immersive experience and yet also allow relaxation. "P" confirmed being able to relax once a feeling of safety was achieved, and found it indeed possible to enjoy the journey while interacting with the installation. When we asked "P" about accessibility, there was a suggestion that we add more representation at both sites. For example, "P" noticed that we did not have any restrooms specially designed for persons with disabilities which made it harder to relax. "P" also considered that 30 minutes was enough for participants to let their guard down and enjoy the experience.

Based on these first results, we started recruiting, first, people with a broad range of disabilities, and, secondly, members of the general public (students and researchers not involved in the project, invited guests, etc.). We divided participants into two groups: (1) subjects and (2) guests. Subjects were primarily people with impairments who were given an extensive questionnaire and a follow-up interview, whereas guests were primarily members of the public and were given a shorter questionnaire.

3.1 Data collection and analysis

Once the participants finished exploring the installation, they were asked to participate in a follow-up interview where they were answered a short questionnaire. The interview was subdivided into four sections:

1. the concept of the installation;

2. the degree of relaxation achieved during the experience;

3. the multisensorial aspects of the experience; and

4. the installation as an awareness-raising tool.

The principal questions addressed in the first section were:

- How easy was it to experience the installation?

- How accessible was the installation?

- Which sites did you prefer the most (beach or forest)?
- What do you think about being able to actively interact with the installation (e.g., changing colors, sounds and decor)?

For the second section:

- What helped you the most to relax?
- Did you feel safe during the experience?
- How representative was the experience?
- Did you notice accessibility representations at both sites and what do you think about that?
- What do you think about the concept of the installation (visiting two inaccessible natural sites)?

The third section addressed:

- What did you think about the visual, auditory, tactile and olfactory stimuli? Did you enjoy them? Did you think their presence enhanced the experience?

The final section, concerned with raising awareness, asked the following:

- Do you consider the رحلة - réhla (Odyssey) installation to be effective as an awareness-raising tool?
- If so, how was it effective? If not, why not?

All the interviews were audio recorded and then transcribed verbatim. To facilitate analysis, the transcripts were systematically coded [38], then analyzed, and finally sorted and categorized. The main results will be detailed below.

3.2 Results

3.2.1 The رحلة - réhla (Odyssey) concept

For most of the participants, this was their first experience of a fully immersive, virtual environment. All the participants from both groups agreed that after putting on the 3D helmet they needed a little time to adjust and understand the interactive environment, but soon after they were able to relax more and start exploring the potentialities of the installation.

> *I have never experienced any virtual experience before [...] It can seem overwhelming at first, but once you get used to it, it kind of worked well for me.*
>
> *(Man: Spinal cord injury; free translation)*

The 3D helmet was not comfortable for all participants. Several experienced significant difficulties in adapting to it. In the middle of the experience, some experienced mild symptoms of headache and eye fatigue, while others found the

3D helmet straps were too tight. The majority of participants, however, made no complaints at all.

> *The helmet was too tight, and even heavy [...] Am I the first one to complain about it?*
>
> *(Man: Congenital limb deformation; free translation)*
>
> *For years I suffered from migraines, and I was scared and hesitant to put a 3D helmet on [...] I honestly didn't even feel it on my head. It is not heavy at all.*
>
> *(Woman: Spinal cord injury; free translation)*

When we asked the participants who visited either site to comment about ease of use, they all agreed that despite the fact that the installation uses a virtual environment, and advanced technology, it remained easy to use and was adapted to their needs.

> *The user interface only displays relevant information. the user is guided in a straightforward manner and transparently through all the steps [...] I didn't need to ask any question to learn how to change the colors or sounds.*
>
> *(Man: Congenital limb deformation; free translation)*
>
> *Before starting the experience, you took time explaining the installation and how to interact with it, and that made a big difference [...] Being unfamiliar with virtual reality, my experience may be different. I first had to look around to figure out how to change the colors and interact with the installation, but once I found the menu, it became easy to play with sounds and change colors.*
>
> *(Woman: Spinal cord injury; free translation)*

رحلة - réhla (Odyssey)'s concept is based on taking the participants to two natural environments, to relax and enjoy themselves. Both environments, whether beach or forest are usually inaccessible. All participants without exception responded positively to the concept.

> *I have never been on a beach, [...] I once tried to go to the beach at Beauport Bay with my friends, only to find out that it's not accessible [...] Putting on the 3D helmet and traveling across the world to find myself on a beach is at the same time overwhelming and exciting [...] Thank you for this opportunity.*
>
> *(Woman: spinal paralysis; free translation)*
>
> *I'm currently living with the help of financial assistance programs. I hardly manage to support myself, traveling and relaxing is not something that I can't afford [...] Now I know that everything is possible with virtual reality.*
>
> *(Man: Congenital limb deformation; free translation)*

When we asked the participants to choose between the two environments and determine which one they preferred, the response was close to an even split between beach (56%) and forest (44%). Most participants are living in Quebec, where forest covers almost one third of the province. Participants were more familiar with greenery and forests than with beaches and sun destinations.

> *I grew up in the Saguenay–Lac-Saint-Jean region, playing with my friends in the forest near to my parents' home, but I have never been to the beach, especially one in Tunisia. [...] It is quite unlikely that I will get another opportunity to visit one, so I tried to spend as much time as I could there.*
>
> *(Man: Hearing impairments; free translation)*

> *I have always wanted to travel and go to a sun destination, but I never thought of visiting Tunisia. I'm so excited to go there especially because it's free and also accessible.*
>
> *(Man: spinal paralysis; free translation)*

> *Water scares me [...] When I was younger I almost drowned. I couldn't enjoy the beach, but I loved being on the top of the cliff overlooking the whole valley, in the forest.*
>
> *(Man: From the guest group; free translation)*

When evoking accessibility during the interviews, many participants noticed how we had included accommodations for assistive technology in our design. Some considered access to all public spaces to be a vested right, while others appreciated our efforts in this regard.

> *When I first got to the room, I noticed all the elements you put into your design to ensure my accessibility such as the wheelchair ramp and the wooden path. I really appreciated the attention and your support.*
>
> *(Woman: spinal paralysis; free translation)*

> *Being able to access public spaces or areas should be available for all, I should not have to think about that. [...]*
>
> *(Woman: From the guest group; free translation)*

The participants associated the accessibility with the fact that the experience was multisensorial.

> *During the experience, I managed to get deeply involved with the installation, it was accessible through the images, the sounds, even the odours and touching the sand.*
>
> *(Woman: From the guest group; free translation)*

All the participants from the subject group agreed that the visual and auditory stimuli had played an important role in the experience.

> *The quality of the images and how realistic both sites were, allowed me to access it all mentally as well as physically. I somehow felt immersed, completely present on the beach in Tunisia, the sounds of the waves and the moisture's odor took me there.*
>
> *(Woman: Spinal cord injury; free translation)*

3.2.2 Relaxation and well-being

When we asked the participants about how relaxed they were during the experience, their answers varied greatly. Indeed, more than half agreed that relaxation and well-being differ from person to person. Most, however, noted that in addition to feeling safe and secure, the presence of many accessibility elements allowed them to let go and relax.

> *From the moment I got to the room, I knew that I could trust you and your experience, [...] All the safety arrangements and the assistive technology accommodations helped me to relax.*
>
> *(Man: Congenital limb deformation; free translation)*

However, a small percentage of participants could not make up their minds whether they felt truly relaxed.

> *I somehow don't know how to feel about this experience. For sure I felt good and relaxed [...] Virtual experiences are new for me, maybe that's why I can't make up my mind.*
>
> *(Woman: From the guest group; free translation)*

The participants confirmed that spending time in natural environments often helps them relax. At the same time, they felt the need to remind us that often these spaces are inaccessible for them. Almost all the participants from the subjects group agreed that being able to relax in spaces such as a beach or forest was only possible because of the accessibility elements that we had integrated into the design.

> *There is no doubt that every time I need to clear my mind, l go to the park near my home[...] It is almost impossible for me to relax with my wheelchair since I am constantly trying to make sure not to get hurt. In this experience, I did not need to do that, [...] I only had to put on the 3D helmet to find myself in your country of origin by the seaside*
>
> *(Woman: spinal paralysis; free translation)*

For the participants trying virtual reality for the first time, they attached special importance to the technology, thereby confirming that VR made the whole experience exciting and raised their level of interest.

> *I always wanted to try a VR experience [...] Experiencing it for the first time with you was so exciting, [...] I know that you wanted me to relax, I couldn't do it at first. I wanted to discover everything. Once I did, though, I was able to relax and I enjoyed the moment travelling between the beach and the forest*
>
> *(Man: Congenital limb deformation; free translation)*

Being able to personalize and customize the installation was positively perceived among all the participants from both groups. In fact, almost all of them agreed that having the opportunity to express their taste in colors, sounds, or even in choosing different physical elements within the white-room gave them a sense of control which helped them lower their guard and enjoy the present moment.

Involving me in the making of the experience through changing the colors made me feel more in control [...] Since my accident I learned to control my things to ensure my safety. During this experience even without being able to fully control every aspect, simply changing the colors and the sounds boosted my self-confidence and helped me to relax.

(Man: Stroke; free translation)

3.2.3 Multisensorial experience

When we presented the رحلة - réhla (Odyssey) concept to the participants, we made a point of mentioning that the experience focused on body sensations and interactions which involve several sensory modalities. This was done so as to accommodate the broadest range of participants and also to enrich and enhance their experience. All participants from both groups agreed that the installation offered different stimuli which helped them during the experience.

I enjoyed every aspect of the installation from the high quality images to the sounds of the birds and waves, everything was perfect. I couldn't stop exploring [...] But what made the difference was the pleasing scents that kept triggering positive memories and elevating my mood.

When we discussed the multisensory aspects of the experience with the participants, they described how they felt about being able to experience the installation through their senses. Some of them qualified themselves as visually oriented, while others as a scent-oriented.

I'm too sensitive to smells and scents [...] I travelled to your home country, Tunisia, through all those pleasant smells and odors

(Man: From the guest group; free translation)

I enjoyed every moment of the experience, but my favorite was the beach at night. Those images took my breath away and I felt like I was present there with you and through your old memories

(Man: Congenital limb deformation; free translation)

Some participants enjoyed relaxing with the birds, waves, and even the waterfall sounds. They managed to let themselves go and start thinking about the experience as an opportunity to travel away from their daily lives.

For a moment I forgot where I was [...] I even chose to close my eyes and only enjoy the sounds and the odors, that made such a difference, I felt secure and relaxed [...]

(Woman: Spinal cord injury; free translation)

3.2.4 Awareness-raising tool

Although رحلة - réhla (Odyssey) was conceived with the primary purpose of offering participants an immersive and interactive journey promoting relaxation and well-being while exploring two natural environments (beach and forest), we also wanted to use the installation as a tool for raising public awareness about the issue of accessibility among people with impairments. Against all expectations, the participants from the guest group almost did not notice our efforts.

> *[...]If you had not asked me about it, I would not have noticed. I was having such a good time that I didn't pay any attention.*
>
> *(Woman: From the guest group; free translation)*
>
> *I did notice the safety arrangements and the assistive technology accommodations and I thought that it is important to have all these elements in the experience since it is designed for all, but I did not understand that you were trying to raise awareness about the issue of accessibility*
>
> *(Man: From the guest group; free translation)*

On the other hand, participants from the subjects group highlighted the efforts made to address the issue through our design, and even advised us to adopt a more proactive approach. It is true we dealt less directly with the accessibility issues than we could have. Participants from the subjects group encouraged us to address the issue more directly to showcase the social and environmental barriers and also to reflect the reality of their life as it unfolds day to day.

> *I understand that the primary purpose of رحلة - réhla (Odyssey) was to offer relaxing spaces, but if you want to raise awareness about the issue of accessibility you need to address it in a more direct manner, [...] Intent to shock and disturb often helps.*
>
> *(Woman: spinal paralysis; free translation)*
>
> *I get what you were trying to do, [...] but I'm not sure that the general public is aware of how much natural environments are inaccessible for us.*
>
> *(Man: Stroke; free translation)*

From the guest group, only a few participants confirmed that from the beginning of the experience they became more sensitive to the accessibility issue for people with disability. Almost all of them were shocked when we mentioned that among the 25 participants with impairments who had taken part in the experience, few had ever been able to physically go to a beach.

> *To be honest I never paid attention to the accessibility issue, maybe because I never considered that going to the beach was challenging even for people using wheelchairs, I think that I need to open my eyes [...]*
>
> *(Man: From the guest group; free translation)*

4. Discussion and conclusion

In summary, our work consisted of developing a methodology for designing interactive and immersive installations that harness virtual reality experiences, with a particular focus on designing for people with disability. This complex project was, ultimately, a considerable success, and we learned a great deal about preparing and implementing such an installation. We framed the design process in terms of "design thinking," an approach that has found favor across a broad range of disciplines and applications for more than three decades. The three stages invoked, which we called "empathy," "ideation," and "experimentation," are widely associated with this design approach although sometimes slightly different labels are used. The empathy stage encouraged us to go beyond the "needs assessment" process typically used as a first step in engineering design, to examine the day-to-day lives of people with disability, particularly, in the study presented here, focused on risk taking. This led to a major restructuring of the proposed project, and emphasized the ever-present need to involve people with disability in all aspects of the design process. Our early efforts orienting the design were also informed by the Cognitive Design methodology developed by members of the team earlier, and led us in particular toward an installation design that would call on as many sensory modalities as possible, to enhance the experience and also provide a sensory experience that would be interesting to anyone, regardless of the nature of their functional limitations. The importance of this early design choice was heralded by many participants during the evaluation stage. Another important issue raised by this work was the idea that definitions of accessibility need to address issues of safety and also social issues, and not be only confined to the physical, or informational environment as is often the case.

Beyond the process of designing the installation, there were also many lessons concerning the content of the experience that was presented to participants. Hence, we drew on universal design principles to determine, for example, the width of the walkways and the configuration of the platforms (for example, ensuring adequate room to turn a wheelchair, etc.). The need to include specific representations of accommodations for disability in the virtual environments was also emphasized both during the design phase, and also in the remarks made by participants after having experienced the installation. Although we incorporated some of these representations, it was clear from the post experience assessment that we could have done more, especially to heighten the use of the installation for raising awareness among a broader public concerning issues of accessibility.

Another feature of the design process we adopted was to integrate the personal vision of the main designer with additional elements, memories, and remarks culled from the experiences of people with disabilities who were consulted throughout the development. This made for a highly evocative experience, characterized indeed by a certain poetry of visual expression, which also was remarked upon by participants in the postexperience assessment. The realism of the 3D environment was also remarked upon and appreciated by participants.

It is also worth noting that the post-installation interviews highlighted the ways in which the installation inspired or even, in some cases, changed the perceptions of people with impairments, concerning what might be possible for them in the future. More could be done both with the development of installations like رحلة - *réhla (Odyssey)* that may have similar transformative effects, and also with longer term assessment to determine whether such effects are sustained in time.

Finally, it is worth noting that the costs for developing the installation were modest, amounting to no more than 12 K$ Canadian for both the virtual and physical components of the environment, not counting the student stipend.

Although for the purposes of this research we developed a particular installation that addressed the interests and needs of people with disabilities, we believe that the lessons learned, as presented in this chapter, could serve other virtual reality design projects, especially in the context of serving the population of people with impairments, but also whenever there is a focus on designing for everyone (i.e., universal design).

Acknowledgements

Our special thanks to the participants who placed their trust in us during the different phases of this research, along with our 3D designer, Jonathan Proulx-Guimond, our technical assistant who constructed the physical environment, Gabriel Gouveia-Fortin, our music consultant, Jocelyne Kiss, our partner for providing scents, *La maison des senteurs*, and finally, the Centre interdisciplinaire de recherche en réadaptation et intégration sociale (CIRRIS) for providing us with a space to host the installation. We also thank the Technologies immersives en réadaptation group within the CIRRIS for partial funding in support of the installation via its seed project funding. The ethical approval for the installation study was sought and obtained in January 2019, from the Research Ethics Board of the IRDPQ.

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Edited by Dragan Cvetković

Virtual reality is a set of technologies that enables two-way communication, from computer to user and vice versa. In one direction, technologies are used to synthesize visual, auditory, tactile, and sometimes other sensory experiences in order to provide the illusion that practically non-existent things can be seen, heard, touched, or otherwise felt. In the other direction, technologies are used to adequately record human movements, sounds, or other potential input data that computers can process and use. This book contains six chapters that cover topics including definitions and principles of VR, devices, educational design principles for effective use of VR, technology education, and use of VR in technical and natural sciences.

Published in London, UK

IntechOpen

ISBN 978-1-83880-862-4