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**Investigating human cognitive abilities and  
emerging performance in desktop virtual reality**

**Doctoral Dissertation**

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**Modeling and Development of Infrastructural Systems  
Doctoral School of Multidisciplinary Engineering Sciences**

**2022**

# Acknowledgements

I would like to express my gratitude to my supervisor Péter Baranyi for his profound belief in my work and the scientific encouragement to start these studies. Completing this dissertation would not have been possible without his unwavering support and guidance through each stage of the process. I am incredibly grateful to Ildikó Horváth for her comments on this dissertation and her support in the past years. I would like to extend my sincere thanks to Ádám Csapó, who helped in many ways with valuable advice and insightful suggestions. I also had the great pleasure of working with Anna Sudár; the importance of those professional and motivating conversations cannot be overestimated. Many thanks to all participants who contributed to the experiments and enabled this research to be possible. To conclude, I cannot forget to thank my family and friends for all their unconditional support throughout my studies.

The author was partially supported by the ELKH-SZE Research Group for Cognitive Mapping of Decision Support Systems.

# Summary

Virtual reality is a dynamically evolving field that includes different technologies that create simulated 3D environments for various applications. It is a heterogeneous technology both in terms of hardware and software. However, their common characteristic is the unique experience of its users, the so-called presence. Presence is the subjective feeling of being inside the virtual environment. The other common factor is the human cognitive and perceptual system, which has a significant role in the virtual reality experience. The present dissertation investigates the role of human cognitive abilities in desktop virtual reality.

The research area presented in the dissertation covers both the field of computer and cognitive sciences: the topic is primarily related to information technology, but for examining the research questions, the application of cognitive psychology measurement methods was essential. In this way, the users' behavior, experience, individual cognitive characteristics, and performance could be measured.

In my research, I have measured the individual spatial memory and mental rotation ability and there was no statistically significant correlation with the efficiency of task completion in the MaxWhere 3D desktop virtual reality. Regarding the sense of presence, I have shown that it correlates with the navigational experience but not the task completion. I also compared 2D interfaces, and I have demonstrated that users are more likely to remember the visual content directly inserted in the virtual environment and the additional information.

# Összefoglalás

A virtuális valóság egy dinamikusan fejlődő terület, amely különböző technológiákat foglal magában, amelyek szimulált 3D-s környezetek létrehozására képesek. Ez egy heterogén technológia mind hardver, mind szoftver tekintetében. A közös jellemző a felhasználók sajátos élménye, az ún. jelenlétérzés (presence). Ez a virtuális környezetben való tartózkodás szubjektív érzése. A másik közös tényező a humán kognitív és percepciós rendszer, amelynek nagy szerepe van a virtuális valóság élményében. Jelen disszertáció célja a humán kognitív képességek szerepének vizsgálata egy asztali virtuális valóság használata során.

A disszertációban bemutatott kutatási terület az informatika és a kognitív tudományok határterületén fekszik: a téma elsősorban informatikai, azonban a kutatási kérdések vizsgálatához elengedhetetlen a kognitív pszichológia mérési módszereinek alkalmazása. A felhasználók viselkedését, tapasztalatait, vagy éppen egyéni kognitív jellemzőit és teljesítményét is ezen módszerekkel lehetséges vizsgálni.

Kutatásaim során kimutattam, hogy az egyéni téri emlékezeti és a mentális forgatási képesség nem korrelál a feladat-végrehajtás hatékonyságával a MaxWhere 3D virtuális valóság asztali verziójában. A jelenlét érzéssel kapcsolatban kimutattam, hogy korrelál a navigációs élménnyel, de a hatékony feladatvégzéssel nem. Összehasonlítást végeztem a 2D-s felületekkel is, és bebizonyítottam, hogy a felhasználók nagyobb valószínűséggel emlékeznek a virtuális környezetbe közvetlenül beillesztett vizuális tartalomra, valamint a kiegészítő információkra.

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# 1. Introduction

*Virtual reality* is a dynamically evolving field that includes different technologies that create simulated 3D environments for various applications. In recent years, it has become widely popular outside of the entertainment industry. In 2018, on the well-known Gartner hype cycle, it was already considered a mature technology [55]. Mature technology means that virtual reality was already used to solve real problems in multiple fields, and also its real-world benefits were recognized. Virtual reality technology has moved beyond the entertainment sector; it gained popularity in new fields, such as education, medical training, engineering, robotics, manufacturing, and industry 4.0.

Virtual realities are often considered as a technology product in which various innovations and developments determine the user experience. However, since humans use these devices, it is essential to take into consideration human characteristics. Such human characteristics could be the classic ergonomic aspects, such as physically comfortable handling of a device or some software ergonomic perspectives. Although in this dissertation, the focus will be on the relationship and connection between virtual reality and the human cognitive processes. During a virtual reality session, various cognitive functions help the user understand what the simulation is, what they see, and how they can use the space. Accurate perception and attention are essential to experience immersion into a virtual world. Navigation in virtual space is based on the proper functioning of perceptual-motor coordination. In addition, the working memory and the existing knowledge base also play a role in the virtual reality experience [151].

## 1.1 Motivation and research goals

Virtual reality is a heterogeneous technology both in terms of hardware and software. However, their common characteristic is the unique experience of its users, the so-called presence. Presence is the subjective feeling of being inside the virtual environment. The other common factor is the human cognitive and perceptual system, which has a significant role in the virtual reality experience. As human perception systems and cognition play a key role in the process of perceiving the computer-generated illusion as space and behaving in it as in reality, the human-centered scientific approach in virtual reality research should be a priority. The systematic research of these characteristics in MaxWhere virtual reality is the paramount objective of the present dissertation.

Of the cognitive functions, the examination of spatial abilities is widespread in virtual realities, as the users of virtual realities (VRs) can experience the spatial characteristics of the simulations thanks to them. Spatial abilities are a group of cognitive functions and skills that are determinants in the processing of spatial visual information and solving problems where spatial information needs to be manipulated. The present dissertation explores the role of spatial abilities in the MaxWhere virtual reality. In particular, the relationship between the individual spatial abilities and the efficiency of task completion in the MaxWhere virtual environment. Another aim is to explore the users' navigational experience and analyze its connection with the measured spatial abilities.

The sense of presence is a unique characteristic of virtual realities from the human-centered perspective. Presence is the experience of "being" in virtual reality, experienced by the users. It is a subjective variable, as it is the users' reaction to the immersion. In this dissertation, I aim to explore the sense of presence in the MaxWhere virtual reality. Moreover, the relationship with individual spatial abilities is investigated. As MaxWhere virtual reality is widely used as a desktop VR, another aim is to compare the presence experiences of the novice and more experienced users.

Human memory performance is a significant aspect of the use of virtual reality, especially in educational context. The MaxWhere virtual reality allows placing 2D documents, figures, or even videos in the 3D space. I would like to measure the memory performance for these highlighted objects. Furthermore, I aim to compare it with a 2D browser display.

Inside a virtual space, it is possible to display several figures and documents in an organized way. This dissertation aims to measure the memory performance for supplementary information that is not in the focus of an experimental task. These research objectives have strong relevance in educational practice, as students can easily memorize the essential information and figures if these are highlighted in the virtual environment.

The overall aim of this dissertation is to investigate human cognitive abilities and the emerging performance in desktop virtual reality.

## **1.2 Dissertation structure**

The dissertation consists of eight chapters. After the present introductory chapter, Chapter 2 presents the theoretical groundings and previous research results in the field of my research. The following four chapters present my research and the concluding theses. Chapter 3 presents my research regarding the role of human spatial ability in the use of desktop virtual reality. Chapter 4 describes my research regarding the sense of presence in MaxWhere virtual reality, a comparison with other VR studies. Chapter 5 presents the results of an experiment about highlighting visual information in desktop virtual reality, and Chapter 6 presents my results about the human memory performance for additional information presented in 3D and 2D environments. Chapter 7 introduces the applications and applicability of the results presented in the dissertations and also some future research goals. Chapter 8 contains the summary of the new scientific results presented in this dissertation.

## 2. Preliminaries

### 2.1 Cognitive infocommunications and digital reality

This section presents the broader context of virtual reality that is in the focus of this dissertation. McLellan [110] stated that virtual reality is a cognitive tool, as this technology was devised to enable people to deal with information more easily. This goal coincides with the aim of CogInfoCom, to extend and enhance human cognitive capabilities [10, 12].

Cognitive infocommunications (CogInfoCom) is an interdisciplinary research field that facilitates the synergy between infocommunications and the cognitive sciences. One of the primary goals of CogInfoCom is to help the effective interaction between humans and computers and expand human cognitive capabilities with the help of infocommunications devices. Furthermore, it aims to provide a systematic view on the co-evolution of infocommunication devices, and cognitive processes [10, 12].

Humanity has reached an inflection point in its social and technological evolution, stated the authors of [11, 150]. They state that human-ICT co-evolution and entanglement could lead to a qualitatively new kind of reality, the digital reality. Digital reality was defined as following [11, 150]:

“A Digital Reality (DR) is a high-level integration of virtual reality (including augmented reality, virtual and digital simulations, and twins), artificial intelligence, and 2D digital environments which creates a highly contextual reality for humans in which previously disparate realms of human experience

are brought together. DR encompasses not only industrial applications but also helps increase productivity in all corners of life (both physical and digital), thereby enabling the development of new social entities and structures, such as 3D digital universities, 3D businesses, 3D governance, 3D web-based digital entertainment, 3D collaborative sites, and marketplaces.”

In this definition, the focus is not on mere technology, but aspects of artificial intelligence and social cognition are also enhanced. It is noteworthy that digital reality is not equal to “all digital solutions”. Integration of the different digital solutions, human immersion and contextuality are key part of the concept [11, 150].

In order to become a significant disruption, technological innovations must meet human demands. Thus, understanding the human user is a significant challenge not just for human-computer interface design but in all aspects of technology development. As many developments aim to make the users’ daily life more effective and less stressful, it is inevitable to observe and understand human capabilities in depth. With this knowledge, the computer can understand the motivations of human users and provide context-dependent solutions during their collaboration. Understanding the needs and limits of human cognition is also essential to help effective human-computer collaboration. For this, analysis of human behavior is an essential tool. In the long term, the aim is to replace the command-based interactions with dynamic interfaces that respect the limits of human characteristics and, with the help of affordances, foster a real collaboration between humans and machines [144].

Virtual reality (VR) technology is an integral part of cognitive infocommunications. It is an excellent example of the previously mentioned co-evolution of technology and human capabilities. First of all, the users of virtual realities are humans. Thus their abilities, skills, and preferences shape the development of technology. Secondly, the concept of virtual reality relies on human perceptual ability, and it is designed to immerse the user into a virtual world through their senses. When somebody is immersed in a virtual environment, several different cognitive functions help them to understand the simulated

environment that they see [151]. Users of virtual reality experience the sense of presence, which can be described as the sense of being inside a real environment. This subjective experience is also based on the human perceptual system. Virtual reality designers should take into consideration the needs of users to create a feasible, usable, and joyful virtual environment for entertainment, education, or collaborative work.

## 2.2 Virtual reality

Based on the Merriam-Webster dictionary, the ordinary definition of *virtual reality* is “an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one’s actions partially determine what happens in the environment” [115]. In the scientific literature, there were debates on the way of defining virtual reality, as earlier definitions typically defined it in terms of specialized hardware. Steuer [140] argued that these device-driven definitions are not acceptable in the scientific literature, as these fail to provide insight into the effects of using these systems to provide a conceptual framework. Steuer enumerated three problems with the technology-based definition: first, the VR systems are recognized based on the presence or absence of particular devices and hardware components. Second, it misses the conceptual unit of analysis for VR, as clearly, the hardware analysis is not enough for understanding virtual reality. Furthermore, the lack of theoretical dimensions, as a dichotomous definition, does not help in comparing different virtual reality systems [140].

Wickens and Baker [151] highlighted five main characteristics that are responsible for the development of a sense of reality regardless of technology:

- Three-dimensional
- Dynamic
- Interactive
- Ego-referenced

- Multimodal interaction

Three-dimensional characteristics can be perspective or stereoscopic but are clearly different from 2D in-plane view. The dynamism suggests that the simulation should be continuous, making it appear more realistic in the same way as movies are more realistic than static images displayed one after the other. Interactivity indicates that the user can interact with, control, and actively navigate the virtual space displayed by the computer. The ego-reference, i.e., one's own point of view, is the basis for immersion and the experienced sense of presence. Using a fixed view can make it harder to develop a sense of presence. Multimodal interaction refers to complementary technologies beyond visuality as a primary modality, such as 3D sound effects, gloves with different sensors, and haptic feedback. The existence of all the characteristics is not a condition; they only reinforce each other's effect [151].

Steuer [140] claimed that VR should be defined in terms of human experience rather than technological perspective, and the key to this is the concept of presence. Presence is the subjective sense of being inside a virtual environment. Thus, *virtual reality* can be defined as *a real or simulated environment in which a perceiver experiences presence*. An advantage of this definition is that it can be applied to past, present, and probably future technologies, as it is not linked to specific devices but the general human experience. Furthermore, this shift of reference from machine to individual perception also specifies the units of analysis; the individual experiences of the users. Steuer also highlighted vividness and interactivity as determinants of the sense of presence. Vividness means the ability of technology to create a sensorially rich experience. Interactivity refers to the level of influence that a user can have in the virtual environment [140].

## 2.3 Role of cognitive functions in VR experiences

As the human perceptual system has evolved for perceiving real-world environments, all mediated or simulated experiences are compared to the standard of the first-person

experiences of the real world [140]. Slater [135] describes two different paths for achieving presence in VR. The first is to create a system with such high fidelity to reality that it becomes indistinguishable from reality. The other approach is to apply the knowledge of the human perceptual system to find the essential parts of the human representation of reality to deliver presence [135]. This second approach is more critical in terms of cognitive science and human-centered research, as it shows that the experience relies on the appropriate stimulation of the perceptual system of the user instead of recreating reality. Immersion and presence are two distinct (but related) terms. Immersion is a technology variable, and presence is the human ‘reaction’ to immersion. Thus, it is possible to experience a high level of presence with a low level of immersion. A general sign of presence is when people behave in the VR in a similar way as in the real world, or when they say, “It is like being there”. This experience arises from the appropriate conjunction of the human perceptual and motor system and the virtual reality technology [135].

The human cognitive characteristics allow experiencing a simulation as virtual reality. Cognition refers to the use of knowledge that involves active processing of information [110]. When the user perceives the sight, first, they have to understand what it is, where they are inside the virtual reality, and where they can go inside this environment. Then they have to understand all other possible movements and actions in the VR. For this, precise perception and attention are indispensable. The navigation is based on adequate perceptual-motor coordination. Furthermore, the working memory and the knowledge base also play a role in the understanding of virtual reality [151]. Thus, the same cognitive processes that allow us to understand and process information from the natural world are also triggered by the virtual reality technology [110].

By considering human characteristics in virtual reality usage or design, affordance is also crucial. Affordances are the distinctive feature of an object when the appearance tells something about its function. The general example is the handle, which helps to use an object and show where to grab it. Natural environments provide a wide range of opportunities to use and manipulate different objects. Computer-based systems typically



have fewer of these opportunities [109]. Although, well-designed virtual environments could also provide context for interaction by placing and configuring virtual objects in a manner that helps the users to interact with them naturally. An efficient and dynamic interface could increase the affordance of the system, which further propagates collaboration. In other words, a general system with a user guide is less effective than a system where users can grasp its function and how to operate it at a glance based on affordance [144].

## 2.4 Desktop virtual reality

Desktop virtual realities are the simplest form of VR, where the 3D high-resolution simulated environment is displayed on a basic 2D screen. The control devices have high variability, although the most common ones are simple navigational controls such as a mouse, keyboards, joystick, or touchscreen. These widely used devices could be advantageous, as the users do not need to learn the use of a new and specific control device to use virtual reality. Although gesture-based interaction could provide an even more natural control in the simulated environment. Additionally, headphones can provide a 3D sound experience. Unique motion controls also could be integrated, such as datagloves or hand tracking systems.

Desktop VRs are sometimes referred to as non-immersive virtual realities, compared to the full-immersive HMD or CAVE-based (cavern automatic virtual environment) VRs. *Immersion is what technology delivers*: the more that a system delivers to displays (in different sensory modalities) and tracks the users' interaction intentions, the more it is immersive [135]. Based on this, desktop virtual realities can be considered less immersive than a head-mounted display and datagloves system. However, it delivers a high-fidelity 3D environment with a certain level of immersion. Thus the non-immersive denomination is misleading. Furthermore, immersion is a fundamental characteristic of a virtual environment. If we recapitulate the human-centered VR definition of Steuer [140] (a real or simulated environment in which a perceiver experiences presence) and compare it with



**Figure 2.1:** MaxWhere virtual reality, displayed on a laptop computer (image source: [4]).

Slater's presence definition (presence is the human reaction to immersion); we can conclude that besides presence, immersion is also an essential characteristic of desktop virtual realities. The lower level of immersion implies the elevated importance of applying the knowledge about the human perceptual and cognitive system to deliver an appropriate presence level in desktop virtual realities.

Desktop virtual realities have significant advantages, such as their technical and financial accessibility and the lack of simulator sickness. In some cases, it is also advantageous that, in contrast to the HMD-based VRs, it does not isolate the user from the outside world. Due to the advantages mentioned above, desktop virtual realities are gaining popularity in education. Furthermore, they support collaborative work. Of course, the type of educational material is essential when VR technology is selected. For example, motion tracking and full-immersive features are more critical for motion and practice-based content than general or more theoretical educational materials.

## 2.5 Role of spatial ability in virtual realities

The desktop virtual realities have the opportunity to become the next step in the evolution of computers, with the transition from 2D to 3D. Different technologies and human factors influence this transition and whether it will become a preferred platform. Displaying three-dimensional spaces on computers raises the question of individual spatial abilities. Are these required for using virtual reality? *Spatial ability* is the skill required to orient or perceive one's body in space or to detect or reason about relationships within or between objects in space. For example, spatial ability is required in map reading and assembling jigsaw puzzles [7]. The question arises whether spatial ability plays a role in using virtual realities. With the spread of different new technologies, who will profit from this as the new method helps them be more productive; the already highly skilled experts in the field or the users with lower ability? Similar questions were asked in education when different new technologies have appeared such as multimedia animations [68, 108], 3D models [80, 97], or virtual learning environments [82, 95, 118]. The question regarding the role of spatial ability is still open; there is no final answer yet. There are two main hypotheses, the ability-as-compensator, and the ability-as-enhancer hypothesis.

### 2.5.1 Ability-as-compensator hypothesis

The ability-as-compensator hypothesis proposes that low spatial ability learners could gain particular benefit from the graphical representations, 3D models, or virtual environments [68, 69, 80]. According to this hypothesis, the low spatial ability students benefit as otherwise, they would have difficulty mentally constructing their own visualization. Thus, the supplementary visual information saves them working memory and reduces their cognitive load. Hays [68] used three types of presentation: only textual, static images, and animated graphics. The low spatial ability learners who saw the animation gained significantly contrasted to those low spatial ability students who did not see the animation. In short-term comprehension, the spatial ability was a significant factor in

learning performance. However, in the long-term understanding, the type of presentation had a statistically significant effect on the subject's performance [68]. In a study with high school students, the researchers compared different spatial abilities and learning effectiveness in two learning environments. A pretest/posttest experimental design compared a desktop virtual reality-based learning environment and a conventional classroom learning method with PowerPoint slides. The results showed that low spatial ability learners were more positively affected by this unique learning environment than high spatial ability learners [95]. Virtual realities provide the possibility of interaction beyond displaying 3D models. This direct manipulation provides benefits beyond passive viewing, especially for students with low spatial abilities. Direct manipulation of the virtual environment facilitates the embodiment of the anatomical structure and helps maintain a clear frame of reference while interacting [82].

### **2.5.2 Ability-as-enhancer hypothesis**

The ability-as-enhancer hypothesis proposes that the already skilled individuals could benefit from the 3D presentation as they have enough capacity left for mental model construction [108]. The benefit of 3D models is to help the students elaborate on a complex object's spatial arrangement. However, students with lower spatial ability became cognitively overloaded by them. On the other hand, the high spatial ability students benefited from the 3D models as their cognitive load did not cross the working memory limits [80].

Anatomy is an excellent example of learning complex structures where spatial relations have a crucial role. The traditional way of learning an anatomic structure involves 2D figures and sections from predefined planes. With this method, the student must mentally create the 3D model from the different sections. The number of different views is also a significant factor. A study [97] examined the effects of learner control and the number of views on the study of brain anatomy. They found the best learning performance was when the students only saw some key views and the control over the learning environment was low. The students with lower skills performed better when they saw only the key

views (instead of multiple views). This result can be explained by the higher cognitive load needed to match the unfamiliar views with the more familiar key representations. In this research, the worst performance was measured when the students had no control over the presentation, and they saw multiple views [97]. Virtual realities differ from classic 3D models as they are much more interactive: beyond watching the object from any viewpoint, the user can also manipulate it. Furthermore, a whole complex environment is displayed around the embedded model.

Navigational tasks are also common in virtual reality studies. According to the ability-as-enhancer hypothesis, better visualization or spatial skills help the user build a better mental model of the space in virtual realities. As a result, these users can be more effective even in other related tasks, such as orientation, and navigation in the virtual environment. Modjeska and Chignell [118] used a 2.5D map view and a 3D (fly-through view) in their study, but they did not find any significant difference between these two conditions. The spatial ability measures were in line with the ability-as-enhancer hypothesis. The users with the lowest quartile of spatial ability performed worse in the search task in the 3D condition. They found that a minimum level of spatial ability was required for effective navigation. The users who reached this level performed well in the experimental task. Thus, above this minimal level, presumably, other factors account for the performance differences [118].

## 2.6 Sense of presence in virtual environments

*Presence* is the experience of the feeling of “being” in virtual reality. Slater defined it as “a state of consciousness, the (psychological) sense of being in the virtual environment” [137]. Presence frequently appears along with the term immersion, and they are firmly related, but the two terms should be separated according to [135]. Immersion is a technology variable. It means what the technology delivers to the user. It is a more objective concept than presence. Thus it could be more objectively assessed, based on the devices and technological instruments. In contrast, presence is a subjective phenomenon;

it is the human reaction to immersion. As different people can react differently to immersion, they can experience different levels of presence in the same virtual reality [135]. Accordingly, the measurement of presence belongs to the field of psychology. From the users' perspective, presence is an experience. For example, after a virtual reality session, the users remember the virtual environment as a place rather than as a set of pictures or as a computer program [136]. Presence is a response to a certain level of immersion. In order to achieve this sense of presence, two different paths are available according to Slater [135]. The first is to construct such high fidelity with a virtual reality system that is indistinguishable from reality. The other approach is to use the knowledge of the perceptual system, to find the crucial characteristics of our representation of reality, and to deliver presence even when the level of immersion is not as high [135].

Several different factors are supposed to contribute to the sense of presence. Steuer [140] highlighted two major technological dimensions that determine presence: vividness and interactivity. Vividness means that the simulated environment is sensorially rich. The formal features define the representational richness of the mediated environment. Vividness is how an environment presents information to the senses. Interactivity refers to the degree to which users of the medium can influence the content or the form of the mediated environment. Furthermore, he draws attention to the user characteristics and individual differences that also affect the perception of presence. The controller naturalness seems like a technology dimension, but it is a subjective variable, as different people have different experiences with each controller. Perceived controller naturalness can predict spatial presence. In other words, a natural interface requires less thinking about control, and the user can more effortlessly feel inside the virtual environment [134]. General computer experience or game playing does not relate to the sense of presence [103]. However, experience with virtual reality helps to focus the attention on the details of the simulated environment instead of navigational tools [128].

Presence is positively correlated with human performance, and learning outcome [116, 132]. Some features of educational virtual environments are especially decisive in terms of learning outcomes. Such an important feature is the first-person view, the non-

symbolic interaction, and the sense of presence [116]. The higher sense of presence helps them to complete their learning tasks more efficiently and successfully and construct knowledge [117]. A 2019 study by Selzer and colleagues showed a medium positive correlation between learning outcomes and presence. In the ten-minute session, those who experienced a higher sense of presence reached higher scores on the test [132].

According to Schubert, Friedmann, and Regenbrecht [130], in virtual realities, presence develops from the construction of a spatial-functional mental model of the virtual environment. First, the technology immerses the sense and body of the user into the virtual reality. Then, different cognitive processes create the mental model of the body in the virtual reality. Finally, the user experiences the sense of being in the virtual environment, which is the sense of presence.

Presence is in the focus of scientific research since the early 1990s. However, as there are several definitions of presence, its measurement also has different variations. Nevertheless, this is not necessarily a bad thing, concluded van Baren and IJsselstein in [147]. In their compendium, they give a comprehensive overview of presence measurement techniques. Besides questionnaires, they included continuous, psychophysical, and physiological measures, and also neural correlates [147]. Questionnaires are the most frequently used methods for the assessment of presence [70]. Usually, these are ordinal scales, such as a Likert scale ranging from 1 to 7. The advantage of questionnaires is that they are easy to administer, applicable for any type of VR, and cheap compared to the psychophysiological measures [61]. In this review, the authors found that there is no physiological measure (EEG, EMG, fMRI, galvanic skin response, heart-rate variability, skin temperature) that collected enough evidence to be reliably used alone, without the subjective evaluation of the participants [61]. The high number of questionnaires (28) in the above-mentioned compendium [147], represents the theoretical diversity of the present concept. The questionnaires as assessment methods presume that presence is a subjective variable, as it can be measured by subjective ratings that require introspection by the responders. Furthermore, most of these are post-test questionnaires, i.e., the participants fill them out after the virtual reality session. Continuous assessment is another type of

measurement where the participants must rate the fluctuation in their sense of presence during the experience. An advantage of this version is the time information, although it may interrupt the user experience. Furthermore, the user can only rate one aspect of the experience, contrary to the post-test questionnaires [147].

A widely used post-test questionnaire is the Presence Questionnaire (PQ), which was developed by Witmer and Singer [152]. PQ measures the degree to which the subject is “...experiencing the computer-generated environment rather than the actual physical locale”. It has three subscales: Involved/Control (11 items), Natural (3 items), and Interface Quality (3 items). The Involved/Control subscale measures the perceived control of events in the VR, the responsiveness of the virtual environment to user-initiated actions, and the involvement of the participant during the VR session. The items of the Natural scale measure the extent to which the interactions and locomotion were felt natural. Finally, the Interface Quality subscale assessed whether the control and display devices interfered with or distracted the users from the tasks.

Another widely used instrument to measure presence is the Igroup Presence Questionnaire (IPQ) [129, 130], which is a combination of previous questionnaires and some newly developed questions. In contrast to the previously presented Presence Questionnaire [152], this questionnaire was developed to explore the components within the presence construct, and the focus was on the distinction between spatial-constructive and attention components. In addition, the IPQ questionnaire was statistically validated and thoroughly tested [129, 130]. It is a fourteen-item questionnaire with three factors: spatial presence, involvement, and experienced realism. Spatial presence assesses the relationship between the virtual environment and the users’ own bodies, the sense of being physically present in the simulated environment. The involvement factor measures the awareness devoted to virtual reality. The last factor, experienced realism, assesses the subjective experience of realism in VR. There is also a general item: ‘In the computer-generated world, I had a sense of “being there”’ [130].



## 2.7 Human memory

Memory is a fundamental cognitive function in our everyday lives: it enables the use of previously encoded information in any mental operation; thus, this is the basis of thinking. Memory allows recalling different previously learned facts, skills, or habits. It also allows learning from previous experiences. Extending human memory capacity is not a new intention at all. The cave paintings from ancient times could also serve this purpose. These paintings encoded stories and information and stored them in the environment. In this way, it helped the recall of information. Later, other new technologies helped to extend human capabilities: paper, printing, and audio or video recording. Maybe virtual environments are next in line, as they can be more than a communication medium; they can also be a memory management tool. Moreover, it can serve as a basis for the "algorithmification" of human learning. For example, the VR can be a platform for the classical virtual memory palace method [43].

The human (or any) memory can be described in three phases: encoding, storing, and retrieving. Encoding means the entering of information into the human memory system, storing refers to maintaining the information, and retrieving is the capacity to find and recall [9]. These phases have a strict order, as retrieving specific information cannot be successful without adequately encoding and storing the information.

### 2.7.1 Visual memory and the picture superiority effect

Human visual perception is the basis of visual memory. In a complex environment, scanning a visual scene is perceived as a smooth and continuous process, but the underlying mechanism is based on a series of rapid, discreet eye movements. The visual short-term memory combines these brief glances into coherent representations. To reach this, it binds together the different perceptual features of the objects and links them to the spatial framework. The visual short-term memory stores this information temporarily.

Semantic coding processes the meaning of the item and relates them to other information in the long-term memory [9].

When an abstract concept is presented, it is stored verbally. However, when a concrete concept is presented as an image, it is encoded into both verbal and visual systems. This latter is the dual-coding theory. This theory is the basis of the picture superiority effect, which is the phenomenon that images are more likely to be remembered than words. The advantage of images over words is present both in coding and in retrieving [123]. Pictures are more easily coded, and human memory is susceptible to the symbolic presentation of information [153]. Another explanation of the picture superiority effect is the higher familiarity and frequency of pictorial objects in our everyday life [8].

### **2.7.2 Presence and memory**

The relationship between different levels of presence and memory performance seems quite ambiguous. When more modalities are involved in the virtual experience, such as tactile, olfactory, audio, and visual, the participants felt more present and increased memory performance for the objects in the environment. Interestingly, the elevated level of visual details related to neither the presence nor memory performance [48]. In the same way, the fidelity of the simulation did not impact the subjective presence or the accuracy of memory performance [106]. On the other hand, for procedural memorization tasks, the higher level of immersion significantly improved the performance [29, 126]. These learned procedures were also successfully transferred to the real-world [29].

### **2.7.3 Virtual memory palace**

Learning is much more than just mere memorization. It requires some preprocessing, which can be quite time-consuming. To learn a complex concept, first, it is necessary to be broken up into smaller, more manageable parts. Then these smaller parts are recalled and placed together to get the original concept. The method of loci, also known as the

memory palace method, is a well-known spatial mnemonic strategy to assist in recall. This method is based on associating all "to be remembered" items with a salient part of a place. Then, when it is time to remember the items, the subject mentally navigates through the imagined place or structure, and by looking at the memorized salient cues, recalls the items. While the individual goes through the memory palace, he can recall the items in a specific order, so the method of loci also enables encoding the order of items. The basis of this method is to spatially organize thoughts and concepts and recall them with the help of visualization.

Virtual reality helps to visualize this kind of mental model. Thus the memory palace is available for the long term. Furthermore, the wide range of possible appearances of virtual spaces contributes to the customization possibilities, which enable a more appealing mnemonic. Another advantage is that it can be manipulated later, and also it can be passed to other users or students to help them study different concepts with this method. Furthermore, the VR can provide constant (visual) feedback for its users about their learning process [43].

Characteristics and effectiveness of the memory palace method were already contrasted to the virtual reality memory palace in several studies [52, 96, 88]. In a between-subject design study, the classic memory palace method was compared to a virtual memory palace method (the subjects had to use a previously arranged virtual environment) and to a control group (uninstructed on study and recall strategy). The virtual memory palace was presented on a desktop computer. The participants had to memorize ten lists of eleven uncorrelated words with the help of one of the above-mentioned three methods. Then they had to recall the words serially. The virtual memory palace method was effective with the briefly presented novel virtual environments. The virtual memory palace method resulted in a higher compliance rate than the classical method, which can indicate that the participants found the virtual memory palace method easier than the conventional method [96]. Another study found that in the long-term retention, there was a difference in favor of the desktop virtual memory palace instead of the uninstructed condition [52].

The level of immersion is another contributing factor in virtual memory palaces. For example, a study compared the use of an immersive (HMD) and desktop VR in a within-subject design. They found that the HMD condition resulted in better memory recall than the desktop condition. Additionally, the participants also felt more focused on the task in the HMD condition [88].

In the sector of education, virtual realities are getting increasingly popular. Digital transformation in education aims to raise the interest and engagement of students and help them in their learning experience. With gamification, personalized learning, and augmented reality, virtual reality is a prominent trend in this transformation. Virtual reality appears in different forms in education: virtual lecturing [47], virtual training [6, 107], field trips in special areas, or museums [57]. As virtual reality gained ground in the industry [14] thus it is important to introduce virtual reality in the education of engineers such as different simulations in virtual laboratories [32, 33, 34, 89, 91, 92]. Virtual reality can engage and motivate students to acquire knowledge [35]. Moreover, it provides visualizations and interactions that are impossible or too expensive to perform in a real environment. According to a meta-analysis, virtual reality-based instruction is highly effective in K-12 (from kindergarten to 12th grade) and higher education [114].

## **2.8 Theoretical groundings of VR and web-based advertising**

### **2.8.1 Web-based advertising**

Throughout history, advertising has appeared on various platforms to reach a broad audience and obtain attention to the promoted product. From the sales messages written on Egyptian papyrus, through the 19<sup>th</sup> century's image with slogan style, advertisements have changed in many different ways to find the most efficient forms to influence the consumers. Nowadays, TV ads and online advertising are the focus of the advertising

industry. As the interest in virtual realities increases, advertisers tend to focus on this new media to exploit its potential.

Along with the increase in Internet users worldwide, online ads have become a fundamental part of the advertising industry. In the first half of 2017, digital advertising revenues in the United States reached \$40.1 billion, which means a unique 22.6% growth in one year [81]. Correspondingly, we can find several advertisements on almost every kind of website. For example, when somebody reads an online newspaper, they can see banner ads at the top, the bottom of the article, or the sidebar, or they can see pop-up ads too. They can also meet with short commercials wedged in between two videos. Various forms of advertisements appeared along with the growth of the internet, but here is a general definition from Louisa Ha for online advertising: Deliberate messages placed on third-party websites including search engines and directories available through Internet access [67]. In my research, the focus is on banner ads, and social media ads are not covered.

The advertising industry widely uses the picture superiority effect, presented in Subsection 2.7.1. Pictures are an essential structural element of advertisements. For a less motivated audience, the visually framed messages were more effective. Consumers with less ability to process information semantically are also more easily reached by visual advertisements [124]. Another advantage is that for a long-term memory effect, a visual message requires less exposure than verbal ads [39]. The order of information processing can also play a role: the visual components are more likely to be viewed before the verbal part. Thus it can generate an expectation about the verbal component [79].

All forms of online advertising originate from print advertising. Therefore they have many similarities in arrangement, text, and graphic design. However, online advertising pushes the advantages of the digital world and supplements still pictures with hyperlinks, various animations, and sound effects to capture consumers' attention. One of the most common formats of online ads is banner ads, where the advertiser pays for space on one or more online pages to display a static or linked banner or logo [81]. These ads are

examined in various studies [36, 53, 67, 98]. People have different attitudes to different ad formats, but it seems that consumers attribute the highest information factor to banner ads and the highest overall positive attitude [36].

An advertisement's effectiveness also depends on the media credibility and content congruence with the web page. The online market requires consumers to make decisions about products without commonly used first-hand, physical experiences. Therefore, credibility has a more significant role in online marketing than traditional advertising. As advertisements never appear alone, they are embedded in non-advertising content; their reliability is judged based on the website and advertiser credibility. Banner ads on credible sites produce a more positive advertising outcome. Content compatibility means that the advertised product matches the website content; thus, consumers find it more exciting and valuable [49]. Nevertheless, this overall positive attitude is not toward the ad itself, but toward the brand and purchase intent [40].

As can be seen, traditional web-based advertisement is a widely examined subject since academics and practitioners are also concerned about finding the most effective methods. However, traditional web-based advertisements share some standard features, including embeddedness, which can be interpreted as constantly breaking the content, even the related ones. These characteristics can be a disadvantage as they can irritate users and evoke ad avoidance. Irritation is another contributing factor to advertising effectiveness. It is essential to realize that advertisements can evoke strong resistance from users as they typically try to block or ignore them. When an individual is attempting to carry out a specific goal, the appearing advertisement is perceived as an aggravation, particularly by those users who understand the online persuasion strategies (larger sizes, animations) [127]. Banner ads are generally displayed on the periphery; they do not directly interrupt the activity of web viewers. In contrast, pop-up ads are one of the most irritating web-based advertisement forms. According to the Interactive Advertising Bureau's definition, pop-up ads (or formally interstitials) are advertisements that appear in a separate window that automatically loads over an existing content window [81]. Therefore, users are forced to react to these commercial messages. For this interruption,

the individuals can respond cognitively, affectively, or behaviorally, which can be both positive and negative for the advertiser. A positive effect could be that because of this unexpected interruption; users will have greater processing and increased memory for the pop-up advertisement [49]. On the other hand, interstitials cause a negative attitude formation which can lead to the avoidance of the ads [66].

Why do consumers find only some advertising irritating and not all of them? The answer is the so-called intrusiveness: the interruption of editorial content [66]. This sounds a bit controversial, as the first objective of advertising is to get noticed, to be as salient as possible; thus, interruption of editorial content should be a vital characteristic of all advertisements. Whereas when the ads were related to the user's task, the participants perceived them as less intrusive [66]. The evoked negative attitudes and reactance could result in ad avoidance and feeling of irritation. Reactance theory is a social psychological theory that describes human behavior as a response to the perceived loss of freedom in an environment. When an individual feels that his opportunities or freedom narrows, the reactance helps to re-establish the control of a situation and a sense of freedom [30]. This reactance is also present in advertising. Consumers actively interpret advertisements and react against the threats of persuasion. As ads are perceived as less intrusive when related to the web user's task, in the same manner, more value is perceived in an ad (more information or entertainment), and it is evaluated as less intrusive.

As described previously, advertisers tend to find new ways and new media to deliver their commercial messages to potential consumers. Virtual reality is a fast-growing field where advertisers are trying to find more effective ways of advertising.

## **2.8.2 Virtual reality advertising**

Advertisers use different methods to evoke the attention of customers. A widespread VR advertising method is to create virtual experiences, where users can get a kind of first-hand information about the product before the acquisition [41]. As an illustration, we can take destination marketing as a promotion tool. Advertisers try to encourage real-

life tourism visits by offering VR experiences. In this field, visual imagery is essential to focus attention on a particular destination [64]. Another type of VR marketing method is avatar-based advertising, where an attractive avatar gives information about a product or helps choose an item in a virtual store. The effectiveness of these different advertisements depends on several factors. For example, the physical attractiveness of a spokes-avatar is a mediating factor [83]. What are the most crucial success factors in virtual worlds? According to Tikkanen and his colleagues, the value for customers, community management, and highly interactive applications can be the most prominent advantages [143].

Displaying three-dimensional spaces is a crucial feature in virtual realities, which advertisers have already established. They realized that 3D images are more persuasive for any customer in an online shopping environment. There are, of course, some differences regarding the type of product: in the case of geometric products (e.g., watch), there is an even more significant effect of 3D than in a case of a material product (e.g., jacket) [46, 99]. The user's individual characteristics are also an essential factor: if a person has a high need for touch to decide, this user is less impressed by the 3D version of a jacket than another consumer who does not feel this need to touch a product before purchasing [46]. Another characteristic of the 3D display is that it enhances the sense of presence in a virtual space and influences product knowledge and purchase intention. This greater sense of presence is irrespective of the type of product (geometric or material) [85]. These examples are part of informational advertising, emphasizing the details and knowing the product.

In contrast, transformational advertisements are those in which the emphasis is on the experience of using the product. For example, a transformational advertisement shows a person feeling adventurous and lively when using a product. This type of ad influences the attitude toward the advertisement and the brand. Researchers found these transformational ads more efficient when they were presented in 3D via a cardboard-type head-mounted device than in 2D [85]. In destination marketing, the virtual reality-based advertisement generated more emotions toward the destination, and the individuals found it more engaging [64].



The exposure effect is a well-known psychological effect that means that customers misattribute the increase of accessibility of a brand as liking the brand. In other words, if an individual is exposed to an advertisement or a product, they see regularly, they are going to interpret this, as they like the product [154]. Another advantage of product placement is that it could enhance the feeling of realism of the virtual space. Correspondingly, there are more ads for real products than for fictitious products in a video game, as this also can increase the sense of presence in this alternative reality [102]. Product placement is that it is less obtrusive. Namely, the media users are less likely to develop the above-mentioned psychological reactance toward the ad [49]. On the contrary, when product placement is compared with billboard placement in virtual realities, the object and brand recall for products advertised on billboards were more significant than the product placement [65].

The presence, the feeling of immersion, is the individual subjective feeling of being in the displayed virtual world. This presence could be a mediator between the ad format (2D or 3D) and the advertisement effectiveness [46, 84]. This presence and high immersion also could evoke the affective engagement of the users [65].

The type of VR device also plays a role in the effectiveness of an advertisement. A head-mounted device or a CAVE can create a higher sense of presence as they are a more immersive system than a desktop monitor, but this does not mean that the advertising is more efficient there than in desktop VR. Moreover, better memory recall and more efficient brand advertising results were found in the case of a VR displayed on a desktop monitor. Another exciting remark of this research is that in the immersive system, the location of an advertisement was more important than its actual size [28]. To sum up prior researches focused on the effects of the 3D visualization of advertisements [41, 46, 99], or virtual prototypes [65, 102], but rarely focused on the comparison between the traditional web-based and VR based 2D advertisements.

## 2.9 Virtual productivity systems

### 2.9.1 Virtual workspaces for effectiveness

Working on a computer often requires using multiple documents simultaneously to see supplementary information next to the main working window. The users need to manipulate more and more pieces of information that are fragmented in different programs and windows. To solve this, users start to switch back and forth between activities that are part of the same project [37]. Card and Henderson compare this with the traditional method of working with papers: every document is grouped and arranged meaningfully on a large desk to enable an effective workflow. The visual availability of the papers helps organize the task, as they become memory cues. Another benefit of the usage of papers is that there is no need to assign names or formal codes to the grouped documents. However, it is inevitable for the 2D operation systems to make an effort to add meaningful names to documents. Different techniques have arisen to solve this problem and enlarge the user's screen. The most commons are alternating screen usage, distorted views, large virtual workspaces, and multiple virtual workspaces [71].

Real-time, synchronous collaboration relies on video or audio conferencing and instant messaging tools. Integrating these session-centric and document-centric collaboration tools in one system was an early objective in designing virtual workspaces. [138]. With the advance of technology, media richness has augmented. This means that an audioconference could convey more cues (tone, pauses) than an e-mail, which reduces the possibility of misunderstanding [45]. Widely used workspace technologies are electronic whiteboards, collaborative document editors, instant messaging applications, calendars, and common repositories [104]. Beyond these tools, knowledge sharing and the coordination of tasks are essentials for the adequate functioning of a collaborative virtual team. Situational awareness is the awareness of the here-and-now states of collaborating team members, which helps them plan the subsequent task. Virtual co-presence can facilitate

situational awareness, which means that individuals feel like they are in the same room with others. This shared context also helps the knowledge exchange [105].

Maintaining focus and keeping the user in the context of her reasoning process is a fundamental requirement of an appropriate computer-based workstation. Direct interaction and manipulation help stay in the task's cognitive zone, which means that it does not interrupt the workflow; thus, it remains one cognitive whole. Also, avoiding actions that take the user outside of the frame of the task, for example, menus, especially the traditional pull-downs where users have to sort through and think about each item, is a way to help to remain focused [62]. One of the most widely known metaphors in human-computer interaction (HCI) is the aforementioned desktop metaphor. Metaphors help to understand unfamiliar processes and places with the help of a well-known situation. However, there is no need for metaphor with virtual reality because it is precisely the environment in which the users work. Thus, users can directly interact with the virtuality without the help of a metaphor [31].

Another phenomenon that suggests using virtual reality as a working environment is the strong need to have an overview. This need is observed even with the use of large, high-resolution displays, where users have stood or sat back at a distance that allowed them to view the entire display at once [51]. On these grounds, virtual reality can answer many challenges, such as situational awareness, task switching on a small screen, and integrating session- and document-centric tools.

### **2.9.2 Current virtual productivity systems**

There are several different virtual reality-based productivity systems nowadays. Most of them use an HMD as a display device. Furthermore, a display on a computer is available in addition to the fully immersive version. In addition, some systems can be opened on a tablet or phone. There's a diverse range of control devices: controllers, gesture controls, motion capture, mouse, and keyboard. Productivity systems require a keyboard, which can be complicated when using HMD. Therefore, in addition to the

virtual keypad, mixed reality solutions are also increasingly available in more systems. These are real-time displays of the physical keyboard to facilitate typing while wearing a head-mounted display.

The display of web windows within virtual reality is quite common. However, the display of other program windows is less widespread. Interaction with 3D objects is also not used widely. Collaboration and communication tools are frequent, and most of these virtual productivity systems display avatars. In the following table, several of these are presented (Table 2.1).

The research, presented in this dissertation, used MaxWhere desktop virtual reality. The results and effects presented in these studies can be generalized to desktop virtual realities in which web pages (as 2D objects) are displayed in the 3D space. The experimental tasks are characterized by requiring navigation rather than interaction with 3D objects. Avatars were not included in the measurements, so the social aspect was not investigated.

## **2.10 Effective workload communication and increased productivity in MaxWhere VR**

The effectiveness of working in a 3D digital environment is a divisive issue. This section presents the results of some comparative studies dealing with this subject. These studies analyzed the sharing methods of workflows and their completion times. *Digital workflows* are defined as the sequence in which individual digital elements are accessed or processed during a digital project.

The study of Lampert and colleagues [94] compared three workflow sharing types: linguistic description and attachments, online interface, and 3D interface. The linguistic description type can be an e-mail that describes the workflow, and the required contents are shared through attachments. The associated elements are not an integrated part of

**Table 2.1:** Overview of the current virtual reality productivity system

	Display	Control	Col- labo- ration	Web win- dows	Other program windows	3D in- teractive object	Avatars
Oculus Horizon Workrooms <sup>1</sup>	HMD	gesture, mixed reality desk with keyboard tracking, controller	✓	✓	✓	✗	✓
vSpatial <sup>2</sup>	HMD	motion track, keyboard, controller	✓	✓	✓	✗	✓
SimulaVR <sup>3</sup>	HMD	keyboard	✗	✓	✓	✗	✗
Softspace <sup>4</sup>	HMD	controller	✗	✓	✗	✗	✗
Virtual Desktop <sup>5</sup>	HMD	controller, touch/physical keyboard	✗	✓	✓	✗	✗
Immersed <sup>6</sup>	HMD, PC	gesture	✓	✓	✓	✗	✓
MaxWhere <sup>7</sup>	HMD, PC	mouse and keyboard, touch controls	✓	✓	✗	✗	✗
Rumii <sup>8</sup>	HMD, PC	controller	✓	✓	✓	✗	✓
Connec2 <sup>9</sup>	HMD, PC	controller	✓	✗	✗	✗	✓
VisionXR <sup>10</sup>	HMD, PC, AR, phone	controller, hand tracking	✓	✗	✗	✓	✓
spatial.io <sup>11</sup>	HMD, PC, tablet	mouse with keyboard, controller, hand tracking	✓	✗	✗	✓	✓
EngageVR <sup>12</sup>	HMD, PC, phone, tablet	controller, keyboard with mouse, touch controls	✓	✓	✓	✓	✓
Vizable <sup>13</sup>	HMD, CAVE, powervall	haptics, hand controllers, full body motion capture	✓	✗	✗	✓	✓

<sup>1</sup> <https://www.oculus.com/blog/workrooms/><sup>2</sup> <https://www.vspatial.com/><sup>3</sup> <https://simulavr.com/><sup>4</sup> <https://soft.space/><sup>5</sup> <https://www.vrdesktop.net/><sup>6</sup> <https://immersed.com/><sup>7</sup> <https://www.maxwhere.com/><sup>8</sup> <https://store.steampowered.com/app/872440/rumii/><sup>9</sup> <https://connec2.nl/><sup>10</sup> <https://www.futurevisual.com/visionxr/><sup>11</sup> <https://spatial.io/><sup>12</sup> <https://engagevr.io/><sup>13</sup> <https://www.worldviz.com/virtual-reality-collaboration-software>

the description. The online interface (Moodle learning management system) also used a text-based description, but the digital contents are listed in some order, and these can also be embedded through links in the description. The third workflow sharing type was the MaxWhere virtual reality. The workflow was communicated through a short description and one file (.pack) that could be opened in the appropriate 3D space, which loaded all the necessary contents into the smartboards. Thus all digital elements were displayed with one click. In this case, the workflow was communicated by the text and the 3D layout. Furthermore, the latter also conveyed the required sequence. The results showed that the users completed the same digital workflow in considerably less time in the 3D interface. The users were 50% faster when they accomplished the task in the MaxWhere virtual reality than in the other 2D interfaces.

Another study [77] proposed a framework to evaluate the effectiveness of digital workflows. They compared the number of required user operations and machine operations. The study showed that the same digital workflows could be completed with 30% less user operation and up to 80% fewer machine operations in a 3D environment than in a traditional 2D interface.

Both studies [77, 94] emphasized the role of digital guidance. Digital guidance means that the user automatically gets access to a logically ordered presentation of the digital contents required to complete the workflow. This spatial organization facilitates the completion. Furthermore, the users need no additional operation to reach this optimized view. The 3D platform can even increase the effectiveness of other web applications by providing a spatial layout [76].

The study of Sudár and Csapó [142] focused on the user interaction in the MaxWhere virtual reality. The study revealed that the users preferred the gesture-based activation method of the smartboards, which is a faster method than the capsule-based method. Furthermore, this method enables one to jump to full-screen mode from any point in the space. The frequency analysis showed preference points in virtual reality that are more frequently visited by the users. While users solve their tasks, they tend to minimize their

movement and navigate naturally to solve their tasks precisely and find a spot where they could look through the required content.

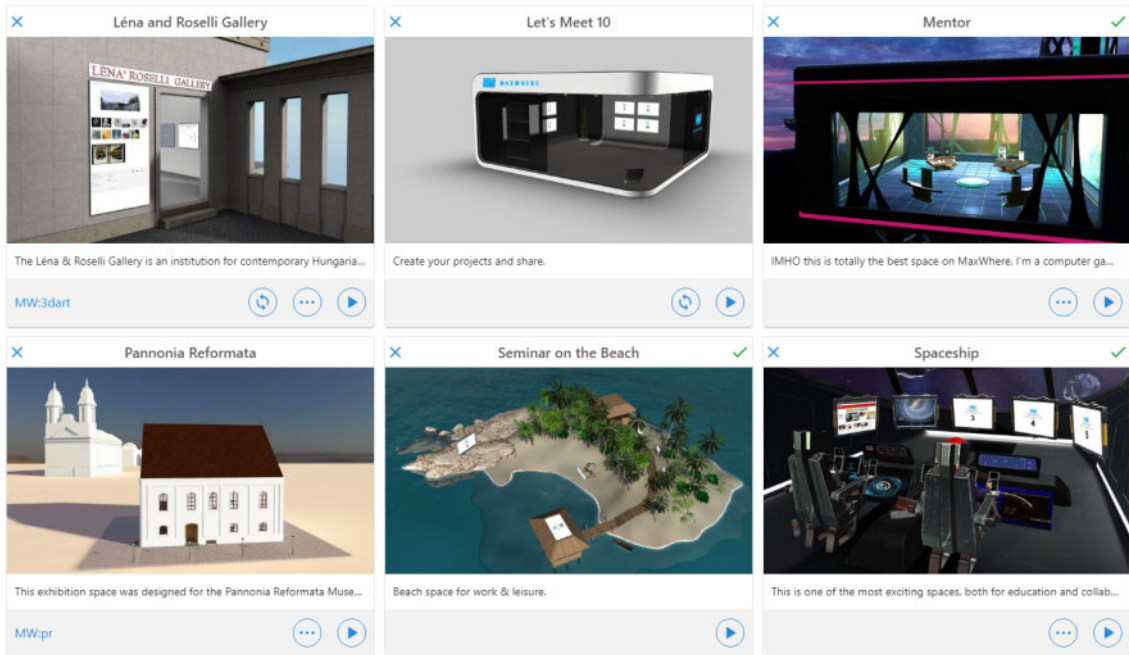
## **2.11 Technical details of MaxWhere VR system**

The MaxWhere virtual reality platform [3] was used in my research; thus, it is presented here in detail. MaxWhere VR aims to move its users and their projects into 3D and let them enjoy the benefits of virtual spaces. In these virtual spaces, smartboards are placed for displaying 2D content. These are full-fledged web browsers that help to integrate several types of 2D content into the 3D world. This virtual reality aims to increase productivity and connectivity with this seamless 3D software.

MaxWhere virtual reality works both as a desktop VR and as a full-immersive VR, with the help of a head-mounted device (HMD). Additionally, it can be combined with a Leap Motion device that detects hand, and finger gestures [120]. As the desktop VR enables to display the simulated environment on a simple 2D monitor, this version is more widely used as it does not require any special or expensive equipment. Furthermore, there is no simulator sickness compared to the full-immersive VRs that use head-mounted devices. Accordingly, in my researches, the focus was on the desktop VR version of MaxWhere.

### **2.11.1 Types of virtual spaces**

This virtual reality platform has several different types of virtual spaces, with different designs and aims. Some spaces are suitable for virtual events such as conferences, exhibitions, and trade shows. Some other spaces are designed for collaborative work, others for educational purposes. Furthermore, there are product showcases and different industrial solutions. The latter can mean a custom-made VR space that helps oversee different operations in one space; thus, the user can overview complex processes. For example, a virtual product showcase is a 3D virtual showroom, where a lifelike, detailed



**Figure 2.2:** Screenshot of different virtual spaces of MaxWhere [3] virtual reality. The first on the upper left is a contemporary gallery, the lower on the left is an exhibition. The other four spaces are designed for creating and sharing projects.

three-dimensional representation of a product is placed [87]. Virtual event spaces such as virtual conference halls have dedicated locations for presentations, Q&A sessions, and virtual networking. Moreover, the shared contents are available for the registered participants, in the VR version or even on mobile through the so-called MaxWhere Lite. This mobile version displays the content of the smartboard, but not the 3D environment.

Virtual exhibitions are virtual galleries that display different types of artworks in 3D or 2D in their actual size, and even interactive contents are available. Furthermore, virtual reconstructions can be realized, visualizations of historical buildings and monuments, even those that do not exist in their original form [58, 60]. It is possible to extend these virtually reconstructed models with other contents, such as any other virtual exhibition or it can be transformed into a presentation room [59].

In education, MaxWhere virtual reality can function either as a learning environment or an administrative framework system. The younger generations prefer the visual pre-



sentation [119], and most students preferred a visual learning style according to a recent study [78]. Quickly finding and selecting relevant information is a growing demand in this century. Based on the result of an eye-tracking study, users find the required information faster in the MaxWhere environment than in a traditional 2D learning management system [145]. The easy sharing method allows the teacher to share the structure of the learning material by displaying the related contents close to each other in the virtual room.

The spatial arrangement of the space can help the students to see and understand the structure of the learning material. Furthermore, the precise information structure can help them to learn and recall the information [43]. The location of the control question has a role too: if the question is located far from the theoretical material, the students memorized more answers, compared to the condition when the questions were located next to the educational content [73]. Additionally, the design of the space also can emphasize the core material, such as visualizing historical buildings with an exhibition inside them [56, 57]. However, several educational spaces in MaxWhere are not for specific content. Any teacher can use these and fill them with their own educational material. Creating a deliberate educational space with heterogeneous sources is more time-consuming, although, in the long term, their student could benefit from it [75].

In higher education, virtual laboratories allow students to experiment and study remotely. For example, different virtual control engineering laboratories are available, where students can explore high-fidelity 3D models designed to be similar to their real-life counterparts. Students can control these models and modify the behavior of the system. Furthermore, the laboratories are part of a complex learning process. Thus the virtual space also contains theoretical information and detailed instructions [32, 33, 34, 89, 90]. Virtual educational spaces of MaxWhere were already used to teach different topics, for example, mathematics [146], sustainability [93], engineering [91, 50], ancient texts [26, 27], and e-health information [35]. Furthermore, it is not only used in higher education but also in secondary schools [44], and in dual education [92].

**Table 2.2:** System requirement of the MaxWhere [3] client software (version: 5.1.7).

	<b>Windows</b>	<b>macOS</b>
<b>Min. OS version</b>	Windows 7	macOS 10.15
<b>System memory</b>	8 GB	8 GB
<b>Min. free disk space</b>	2 GB	2 GB
<b>Min. GPU</b>	NVidia M820	

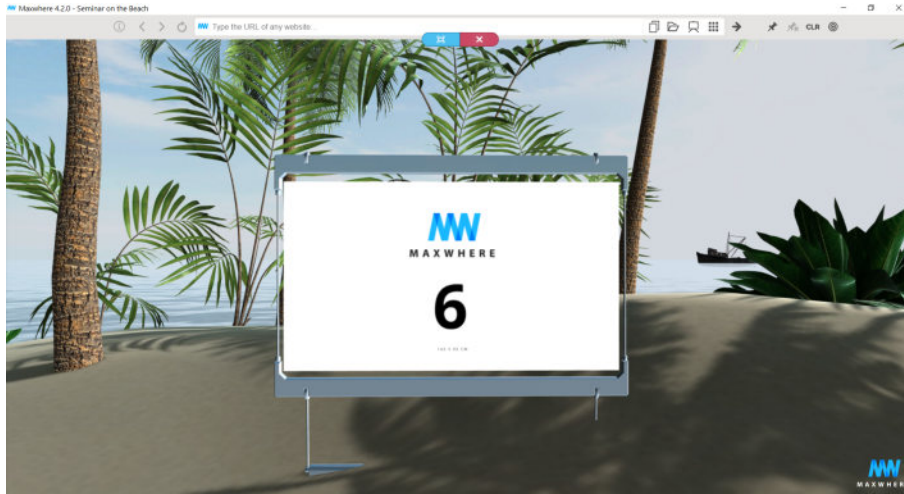
### 2.11.2 Technical requirements

The latest version of MaxWhere client software can be downloaded from their homepage [3] and can be installed free of charge for personal use on a computer running Windows or macOS. The recommended system requirements for both available operation systems (for version: 5.1.7) are specified in Table 2.2. The MaxWhere client runs in a separate window on the computer. The user can download different interactive spaces from the MaxWhere Store that contains a short description of each space. These spaces are packages of digital content that include a 3D graphics environment with interactive operational logic, connected software functionality, and related content. After installation, these units can run as an independent application on MaxWhere. Possible interactions with a running package can be 3D spatial interactions such as navigation or clicking on 3D objects or 2D web interaction (opening local digital content or opening web content).

### 2.11.3 Displaying 2D elements: Smartboards and control panels

In the MaxWhere virtual reality spaces, several so-called smartboards are located. These integrated 2D screens allow users to display and share content from the web and from their devices. The smartboards are individual web browser tabs that can open web contents, web applications, and local digital contents such as .png, jpg, .pdf, .mp4, and other files.

In the current version, smartboards are located in predefined locations of the space. The user has control over its content, but not the size, position, or aspect ratio. The



**Figure 2.3:** Screenshot of a smartboard in MaxWhere [3] virtual reality. At the top of the image, there is the address bar to control the content of the smartboard. Under the address bar, the blue and red capsules are located to set the smartboard into full-screen mode and leave the smartboard.

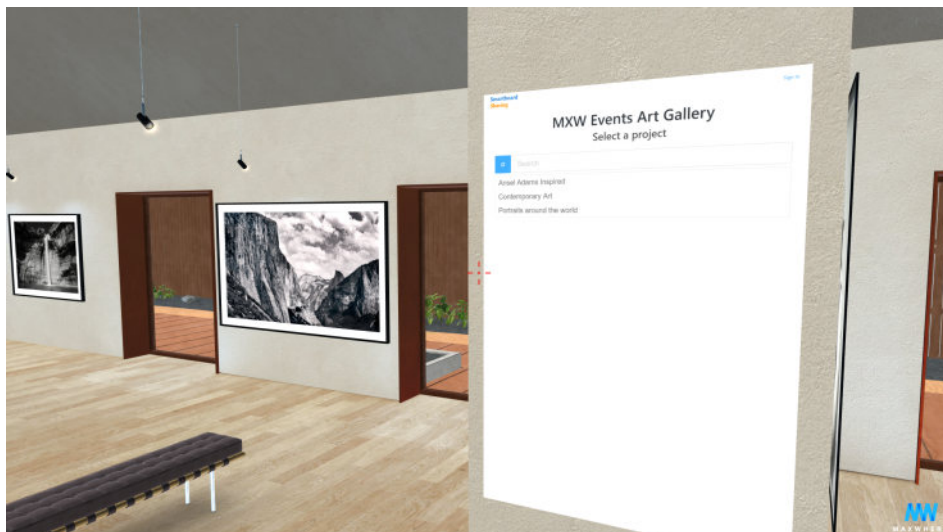
most common ratios in the spaces are 4:3, 16:9, and A4. The latter is ideal for displaying documents. The resolution of the smartboard is set automatically. As these smartboards are individual web browsers, there is an address bar at the top of the smartboard with a visible URL (Fig. 2.3). The URL address can be saved with the pin button and also exported; thus, it can be given to other users in .pack format. A pack is an archive file that can be exported from the MaxWhere environment and contains copies of references to the user's content as well as an optional list of 3D positions and orientations of the 3D template [3]

There is another option to share the contents of the space if there is a control panel. The control panel displays the names of different projects that define the contents of the smartboard in the space. Thus the content of all smartboards can be changed with one click. This feature is useful in educational spaces to share different chapters of the teaching material or in gallery spaces to change the exhibited artworks (Fig. 2.4). Furthermore, these control panels can be reached through a website; thus, they can be edited even on mobile devices.

If the user wants to activate a smartboard, the 3D navigation mode has to be left and switched to the 2D mode. There is two way to activate a smartboard: gesture-based and capsule-based [142]. The left click of the cursor can activate the smartboards. In this way, the smartboard window is activated while the user remains in the same location in the virtual space. If the user wants to set the smartboard window to full screen, the user has to click on a blue icon ("capsule") that appears right under the address bar of the smartboard (Fig. 2.3). To leave the smartboard and return to the 3D navigation mode, the user can click on the red capsule. The other way to activate a smartboard and jump to full-screen mode immediately is more natural, as it needs only a double click on the smartboard. To deactivate the smartboard, the user has to move the cursor to the left or right edge of the screen.

#### 2.11.4 Navigation

MaxWhere virtual reality uses an artificial locomotion technique, as it utilizes an input device. The users have a first-person view, where the viewpoint can be oriented and navigated, although they do not have any visual representation. Therefore, this



**Figure 2.4:** Screenshot of a control panel in the Gallery Demo space of MaxWhere [3] virtual reality. By clicking on the listed project names on the smartboard, the contents of the smartboards are changed.

setup can be considered an avatar condensed to one point without a body. The users can alternate between the 2D and 3D modes with the right click of the pointing device. The 3D mode serves for navigating in the virtual environment, and respectively the 2D mode serves for navigating on the smartboards and activating the menu. The 2D mode allows the user to alternate between different computer programs, which is helpful if the VR is used simultaneously with other software. In the 2D mode, the cursor functions as in any other program. The 2D mode is automatically activated when the user activates any smartboard. By leaving the smartboard, the cursor is automatically used again for navigation in the virtual environment.

For navigating in 3D, the CogiNav technology [13] is used. CogiNav is a context-dependent solution for navigation that allows the users to position themselves relative to their previous location or relative to other objects. The developers of MaxWhere VR recommend using an external mouse with two buttons and a scroll wheel for the best experience, although it also works with a touchpad or touchscreen. Touchpads having two buttons function the same way as the mouse. Alternative key combinations are available for touchpads without buttons to substitute for holding down the touchpad buttons. The detailed navigational instructions are presented in Table 2.3. Below, the navigational operations are listed and briefly described (with the use of the mouse as the default control device):

- *Viewpoint orientation:* The viewpoint orientation could be controlled continuously with the help of the mouse. It serves to look around in the virtual environment.
- *Moving forward and backward:* For moving forward and backward, the user has to roll the scroll forward or backward.
- *Lifting:* The user presses the left button of the mouse and moves the input device, then the view moves on a fixed vertical plane.
- *Spherical orbit:* The viewpoint moves along the latitude and longitude of a sphere that surrounds the selected object. For this navigation, the user has to focus on an

**Table 2.3:** Navigational instructions of MaxWhere (version: 5.1.7) on Windows and macOS for the three different control device (mouse, touchpad, touchscreen) [4].

	Mouse	Touchpad	Touchscreen
<b>Viewpoint orientation</b> (look around)	Move the mouse	Move your finger on the touchpad	Move your finger on the touchscreen
<b>Moving forward and backward</b>	Use the scroll wheel	Swipe your fingers	Swipe your finger on the right side of the screen to zoom in or out
<b>Lifting</b> (moving in a straight line up and down or left and right)	Hold the left button down on your mouse	Hold down the SHIFT (Option) key and move your finger on the touchpad	Hold one finger on the top left corner and swipe with~another
<b>Spherical orbit</b> (around an object)	Hold down the right mouse button	Hold down the CTRL (Command) key and move your finger on the touchpad	Hold one finger in the bottom left corner and swipe with~another
<b>Fly</b>	Hold down the scroll wheel and fly around smoothly	-	-

object, press the right mouse button, and move the device. The scroll can modify the radius of the sphere.

The analysis of the navigational operations and examples are presented in detail in Subsection 2.12.3.

## 2.12 Navigation analysis of MaxWhere VR

As the habit of using desktop VRs and full-immersive VRs is slightly different, the expectations differ. In a full-immersive VR, there is a great emphasis on the immersive experience to be as close to reality as possible. For example, in virtual training, beyond

the realistic environment, realistic interaction is also essential for improving behavioral skills [38, 6, 107]. However, in a desktop virtual reality, where users sit in front of the display and navigate with a mouse, precise and accurate navigation is more important than real-world resemblance. Moreover, MaxWhere VR aims to be used for everyday tasks with easily accessible devices: users primarily work or study in these virtual spaces. Thus, it is crucial to have an easy-to-use and easy-to-learn navigation design besides precise and accurate navigation.

### 2.12.1 Interaction fidelity

*Interaction fidelity* is the objective degree of exactness with which real-world actions are reproduced in an interactive system [112]. Interaction designers strive to create realistic and natural interactions to increase usability and user performance. Although the interaction fidelity is a U-shaped curve with user performance; thus non-natural interaction techniques can also have high user performance [113]. In MaxWhere VR, the real-world actions are reproduced by a pointing device, mainly by a mouse, a non-natural interaction technique.

The level of interaction fidelity can be assessed with the Framework for Interaction Fidelity Analysis (FIFA) [111, 113]. As FIFA compares navigation to real-world navigation, e.g., walking, it is not surprising that a desktop VR that uses the mouse as a control device has a low level of interaction fidelity, especially in the biomechanical symmetry. Biomechanical symmetry compares which body segments are involved in the real world tasks and the interaction (anthropometric symmetry), the reproduction of body motions (kinematic symmetry), and the involved forces (kinetic symmetry). These components have a very low level in desktop virtual reality when navigation is compared to natural walking. Since interaction fidelity is a U-shaped curve with user performance, a technology with a low level of interaction fidelity can have better user performance than a mid-fidelity technology [113].

## 2.12.2 Controller mapping

The mouse is a widespread device that is familiar to most computer users. As the PC users are accustomed to the mouse, with experience, it is perceived as very natural [148]. The perceived naturalness of a control device can be more important than the objective naturalness or its type of mapping. For example, in the study of Seibert and Shafer [131], the spatial presence values depended on the perceived controller naturalness, regardless of what controller type was used.

In the typology of controller mapping, the mouse and touchpad are considered natural, directionally mapped interfaces. Directional mapping means that there is a correspondence between the directions used to interact via the control device and the results on the screen [134]. A great advantage of this natural mapping type is that physical analogies can lead to immediate understanding [121]. Additionally, naturalness is a psychological state that depends on both technology, and individual differences [134], such as previous experiences and perceived naturalness [131].

## 2.12.3 Navigational operations

The navigational operations of MaxWhere do not have on/off characteristics, but they are continuous. In terms of understanding and usability, it is a cardinal feature that MaxWhere translates the mouse motion in an analog way. The human perceptual and nervous system has evolved to fit the nature of physical signals. Accordingly, a person can easily understand analog systems [122]. In the following, the basic navigational operations are presented with their type of mapping. These basic movements can be used only with one hand. Moreover, these operations can be easily understood and can be easily combined too.

- *Moving forward and backward*

The user has to roll the mouse's scroll button to move forward and backward.

This directionally mapped navigation is easy to understand, as it is widely used.



Although for long distances the continuous scrolling can be inconvenient. For reaching a distant smartboard, users can activate it with a double click and jump to its full-screen mode (gesture-based activation mode).

- *Lifting*

Lifting is the navigational operation, when the user presses the mouse's left button and moves it, which results in moving on a vertical plane. Moving on a vertical plane does not resemble any natural human movement, although it is practical in this virtual reality, as the smartboards that display 2D content can be placed in the same plane, thus this navigational operation helps to change the position to focus on another one easily. Lifting is also a directionally mapped navigation method.

- *Spherical orbit*

The spherical orbit allows the user to move around a selected point of an object by pressing the right mouse button and moving the device. Orbital movement is ubiquitous in CAD software, as it is suited to observational tasks [86]. The spherical orbit of MaxWhere allows the users to observe an object from all sides; or with a greater radius, it can give an overview of the virtual environment. As MaxWhere has several educational and exhibition spaces where different 3D models are presented, this navigational operation is quite useful, even if it is not so common in virtual realities, as this is not related to any natural human movement. For example, in the real world, we grab smaller objects and rotate them in our hands to observe or walk around the bigger objects. Therefore, even though it does not relate to a real movement, it relates to the everyday behavior of observation.

The MaxWhere virtual reality provides a unique navigational method for its users by allowing an easy orbit function besides the more widely used zooming and panning operations. These functions are achieved with a general control device, a mouse with two buttons, and a scroll wheel. The spherical orbit is widely used in engineering software, but as it is not related to a specific human motion, it is less frequent in VRs where high interaction fidelity is the aim.

The mouse seems to be an advantageous control device since MaxWhere can be used as a desktop virtual reality: it is familiar to the users and perceived as natural. Furthermore, the analog characteristics of this navigation enable the user to understand and learn the control methods easily.

## 3. Thesis 1.

### Role of human spatial ability

**Thesis 1.** I have examined by a cognitive psychological measurement the relationship of individual spatial abilities (spatial memory, mental rotation) with task performance and subjective navigational experience in desktop virtual reality, and there was no statistically significant correlation between the measured variables.

*Navigational experience:* How natural and automatic the movement in virtual space is. A better navigation experience means more natural, automatic navigation.

References: [19, 20] ▪

This chapter presents my results regarding the role of human spatial abilities in MaxWhere virtual reality. The related theoretical groundings were introduced in Section 2.5, presenting the two main hypotheses (ability-as-compensator, ability-as-enhancer) regarding the role of individual spatial ability in the use of virtual reality. This part of the dissertation is structured as follows: Section 3.1 contains the details of the experiment, and Section 3.2 presents the results of the statistical analysis. Section 3.3 discusses these results, and my related these is in Section 3.4.

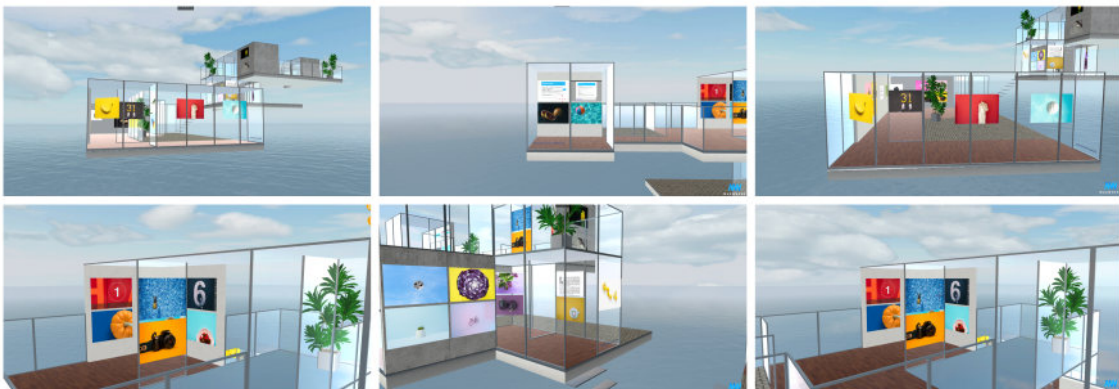
## 3.1 Methods

### 3.1.1 Experimental task

In this study, the Glassy space of MaxWhere (version: 2.4.0-b16) was used. This virtual space is a three-floor, modern glass and concrete building above a serene sea. This space was designed for presentations and online exhibitions, so it has a relatively high number of smartboards (40). The smartboards are on the open walls of the building, also inside and outside (Fig. 3.1). The participants used an external mouse with two buttons and a scroll wheel to navigate the virtual reality.

The subjects had to complete different tasks in the virtual space. Thus they must navigate in the whole virtual space. In the initial view, the users found themselves on the top floor of the virtual building. They saw the instructions and a webpage, which contained the spatial measures, the experimental tasks, and all other questions. On the other smartboards, images were displayed (source of images: unsplash.com). Different objects, numbers, or titles were presented in front of a plain colored background in these pictures. Furthermore, there were two smartboards with documents in PDF format.

To solve the tasks, the participants had to navigate in the space and answer several questions related to the displayed digital contents, and their arrangement (e.g., How many



**Figure 3.1:** Screenshots of the experimental task in the Glassy space of MaxWhere [3] virtual reality.

images with yellow backgrounds are on the ground floor? How many pages are there in a given document?). Then, subjects had to indicate their answers on the webpage displayed on the third floor. They could also use the TAB key to get back to this main area. Twelve points were the highest possible score in these tasks.

### 3.1.2 Navigational experience

Participants had to rate their navigational experience after completing the task in VR. They had to indicate their agreement with five different statements related to their experience in the virtual space on a ten-point Likert scale:

- “I moved confidently in the space.”
- “I felt that I was controlling my movements in space.”
- “I had difficulty navigating to the place where I wanted to go.” (reverse-scored item)
- “Navigation in virtual space was automatic for me.”
- “I felt natural moving in the virtual space.”

The Cronbach’s  $\alpha$  of the scale was 0.883. Therefore this scale can be considered reliable. The Hungarian version, used in the study, is available in the appendix A.2).

### 3.1.3 Measuring spatial abilities

Both spatial ability tests and the experimental tasks were presented with the help of the Psytoolkit [141] software 2.5.2 version. Participants were instructed to use the fullscreen mode of the smartboard during the spatial ability tests to avoid any visual distraction by the virtual space in the background.

- *Measuring spatial memory: Corsi-test*

The online version of the classic Corsi-block tapping test [42] was administered.

This test measures the short-term coding and retention of spatial information. There were nine squares in the same color on the screen. Some blocks blinked in a different color in a random sequence. The first sequence consisted of two blocks. Then the participant had to click with the mouse on the block in the order of the blinking sequence. Finally, they had to click on the “done” button when they finished. Then, they received feedback about their performance. They received a longer sequence (more blocks) if they completed a sequence correctly. If they did it wrong, they got one more chance. If they repeatedly failed to repeat the sequence, the test ended. They received their score (the Corsi span): the number of correctly memorized blocks.

- *Mental rotation task*

In the mental rotation task [133], the subjects had to imagine what a stimulus would look like if it were rotated. In this online version, the participants saw three figures. The top one was the target image, and they had to indicate which one of the two others at the bottom matches the target on the top of the screen. Matching means that it is the rotated version of the stimulus. To solve the tasks, the participants had to rotate the figures mentally. Mental rotation time is the time needed to rotate one item in milliseconds. 2D stimuli were used in this implementation. Users first solved five practice trials and then the ten experimental tasks.

### **3.1.4 Procedure**

The experimenter presented the procedure and instructions briefly (these instructions were also visible on one of the smartboards of the VR).

1. The experimenter instructed the subjects to use the full-screen mode for the first two tasks: the Corsi test and the mental rotation task.
2. After completing these two tasks, the participants were informed that the fullscreen mode is not obligatory during further tasks.

3. After completing all experimental tasks, there was no further need to navigate the virtual space. The participants had to complete the remaining questions on the top floor of the building. They rated their navigational experience. Then, they indicated if they knew the MaxWhere software before and how much time they had already spent with it.
4. Next, they indicated if they regularly use other 3D software (games or designer programs). Finally, they answered basic demographic questions.

On average, the experiment duration was 14 minutes (SD: 4.7). The whole experiment was conducted in Hungarian.

### **3.1.5 Subjects**

Thirty-six participants took part in the experiments. In the final analysis, 31 individuals' data were examined. The other five were excluded due to data loss or misunderstood of the experimental task. The mean age was 20.5 years (SD: 3.4). Twenty-five men and six women took part in the experiment.

## **3.2 Results**

The results are presented in two subsections. Subsection 3.2.1 presents the results of the examination of the relationship between the scores of the experimental task and the individual spatial abilities, such as the Corsi span and the mental rotation skill. Subsection 3.2.2 presents the results regarding the navigational experience. The results of the descriptive statistics are presented in Table 3.1.

**Table 3.1:** Descriptive statistics of the examined variables of the role of spatial abilities experiment.

	Mean	Standard deviation
<b>Corsi span</b>	6.2	1
<b>Mental rotation score</b>	8.4	1.4
<b>Reaction time of correct answers in the mental rotation task (ms)</b>	6573.3	2087.9
<b>Score of the experimental task</b>	9.6	1.6
<b>Navigational experience (1-10)</b>	7.04	2.19

### 3.2.1 Spatial abilities and experimental task

A Spearman's rank-order correlation was used to assess the relationship between the Corsi span and the score of the experimental task. There was no significant correlation between the two variables,  $r_s(28)=0.09$ ,  $p=0.635$ , 95% CI [-0.279, 0.436]. There was no significant correlation between the score of the experimental task and the mental rotation score ( $r_s(29)=-0.174$ ,  $p=0.351$ , 95% CI [-0.497, 0.193]) nor the reaction time of it ( $r_s(29)=0.148$ ,  $p=0.426$ , 95% CI [-0.217, 0.478]). Overall, there was no significant correlation between the examined variables which means that the obtained scores for the experimental tasks do not relate to either of the measured spatial abilities.

### 3.2.2 Spatial abilities and navigational experience

The navigational experience and the score of the experimental task were not related, according to Spearman's rank-order correlation,  $r_s(29)=0.068$ ,  $p=0.718$ , 95% CI [-0.294, 0.412].

The navigational experience was not related significantly to any of the measured spatial abilities, such as Corsi span ( $r_s(28)=-0.137$ ,  $p=0.471$ , 95% CI [-0.474, 0.235]), mental rotation score ( $r_s(29)=0.09$ ,  $p=0.63$ , 95% CI [-0.273, 0.431]) or the reaction time of the correct mental rotation answers ( $r_s(29)=0.133$ ,  $p=0.475$ , 95% CI [-0.232, 0.466]).



Therefore, the present experiment did not show any statistically significant correlation between the navigational experience and the individual spatial abilities or the performance of the experimental task.

### 3.3 Discussion

This chapter investigated whether there is a relationship between the effectiveness of completing a task in VR and the user's individual spatial abilities, namely the spatial memory (Corsi span) and the mental rotation ability. The present measurement could not show any significant relationship between these variables. Therefore, it could mean that using this type of desktop virtual reality is neutral to the individual spatial memory and mental rotation ability.

The relationship between virtual reality and spatial abilities is quite ambiguous. The ability-as-compensator hypothesis mostly appeared when students had to learn a complex 3D model, and the virtual reality helped them to reduce cognitive load and save working memory [68]. The ability-as-enhancer hypothesis was also present in research where instead of a 3D model, a navigational task was the main interest. They found that a minimum level of spatial ability was needed for effective navigation [118]. The results presented in this chapter show a similar pattern, as there was no significant relationship between the spatial ability measures and task performance. Measuring the threshold of minimal spatial ability for completing the task was not part of this research, but this could explain the results.

This study aimed to model an everyday usage of the MaxWhere virtual space and measure its relationship with individual spatial abilities. In the experiment, a relatively large virtual space was used. In educational settings, smaller spaces are more common, and these spaces are also more concentrated. The most important smartboards and information are placed in one central area. Thus, less navigation is needed. It is also

important to point out that in the MaxWhere VR, the CogiNav technology is used, designed to make navigating seamless in 3D virtual spaces.

### 3.4 New scientific results

The results of the measurement, presented in this chapter, could not show any relationship between the measured spatial abilities and the experimental task requiring navigation. This probably could mean that students with higher or lower spatial abilities can have the same benefits when using this kind of virtual reality.

The MaxWhere virtual reality uses general devices to immerse the users into a 3D space. As contributing human factors to the transition from 2D to 3D technology, spatial memory, and mental rotation skills research seized in this research. The results showed that these skills do not play a role in this transition (in the case of MaxWhere VR), as they are not related to the use of this virtual reality. This result could suggest that the MaxWhere VR could be used by anyone, independently of their spatial memory or mental rotation skill.

**Thesis 1.** I have examined by a cognitive psychological measurement the relationship of individual spatial abilities (spatial memory, mental rotation) with task performance and subjective navigational experience in desktop virtual reality, and there was no statistically significant correlation between the measured variables.

*Navigational experience:* How natural and automatic the movement in virtual space is. A better navigation experience means more natural, automatic navigation.

References: [19, 20] ▪

## 4. Thesis 2.

### Sense of presence in MaxWhere virtual reality

**Thesis 2.** I have demonstrated by a cognitive psychological measurement that the sense of presence and spatial presence positively correlates with the subjective navigational experience in desktop virtual reality.

References: [21, 22, 24] ▪

This dissertation chapter summarizes the results regarding the sense of presence in MaxWhere virtual reality. As the sense of presence is an elementary characteristic of virtual reality (details in Section 2.6), and several published studies showed a positive correlation with learning outcomes [116, 117, 132]. Thus, measuring the sense of presence in the MaxWhere VR was required to understand the users' experience. One aim was to assess the presence profile of MaxWhere, which shows its strengths and weaknesses among the different presence components and compare it with other desktop virtual realities. However, as presence is not a unitary construct and has several different ways to measure, this comparison was only possible with those studies that used the same measurement method, in this case, the Igroup Presence Questionnaire [129, 130]. Another aim was to assess the relationship between the level of presence, the performance in VR, and the subjective navigational experience. During the experiment, another research question arose, whether there is any difference between the novice and more experienced users.

The theoretical groundings of the presence concept are explained in Section 2.6. The general details of the measurements are presented in Section 4.1. The results are presented in the following three sections. First of all, some grounding results are presented: the presence profile of the MaxWhere VR along with a comparison of presence results in other desktop virtual studies from a database (Section 4.2). Section 4.3 is a comparison of the presence ratings of novice and more experienced users. Then Section 4.4 describes the relationship between the presence score and the subjective navigational experience. The final section of this chapter presents discusses the new scientific results (Section 4.5).

## 4.1 Methods

### 4.1.1 Igroup Presence Questionnaire (IPQ)

The sense of presence was measured by the Igroup Presence Questionnaire (IPQ). The IPQ is a 14-item questionnaire [129, 130]. Each item is on a seven-point scale from zero to six (lower scores indicating disagreement). The IPQ has three subscales: spatial presence, involvement, and experienced realism. The Hungarian translation used in this study is available in the appendix A.1. Spatial presence assesses the relationship between the virtual environment and the users' bodies, the sense of being physically present in the simulated environment. The involvement factor measures the awareness devoted to virtual reality. The last factor, experienced realism, assesses the subjective experience of realism in the virtual environment. There is also a general item: 'In the computer-generated world, I had a sense of "being there"'.

In the present measurement, all subscales of the Igroup Presence Questionnaire had high reliability, all Cronbach's  $\alpha$  coefficients for the subscales of the IPQ questionnaire were above 0.7 (detailed results are in 4.2.2).

## 4.1.2 Navigational experience

The participants had to rate their navigational experience in the virtual space at the end of the experiment session on a ten-point Likert scale. Details of this scale is presented previously in Section 3.1.2.

## 4.1.3 Procedure

The experimental task was the same as presented in Section 3.1.1. After completing the experimental task, the participants evaluated their navigational experience and filled out the Igroup Presence Questionnaire (IPQ). Finally, at the end of the experiment, subjects answered basic demographic questions, and they had to indicate whether they used the MaxWhere software before the experiment.



How many pictures with a yellow background can be seen on the ground floor? (choose one)

- 0/1/2/3/4/5

What is the color of the background of the image depicting the statue? (choose one)

- red/purple/blue/yellow/white

How many images of cameras can be seen in space? (choose one)

- 1/2/3/4

What fruits are visible on the ground floor? (multiple answer)

- lemon/banana/ananas/orange/apple/peach

**Figure 4.1:** Virtual space of the experiment, and some example questions.

#### **4.1.4 Subjects**

Thirty-six participants took part in the experiments. In the final analysis, 31 individuals' data were examined. The other five were excluded due to data loss or misunderstood of the experimental task. The mean age was 20.5 years (SD: 3.4). Twenty-five men and six women took part in the experiment.

## **4.2 Level of presence in MaxWhere VR and a comparison to other VR studies**

Although presence is a subjective variable and not directly related to the technological details of virtual reality, the user's presence experiences in a particular application or virtual reality can allow a more precise understanding of the given virtual environment. From the subjective ratings, the presence profile of an application or technology can be plotted, which can show its strengths and give an overview of the ratio of the different presence components. Besides the presence profile, the IPQ scores of MaxWhere VR is compared to two other desktop virtual reality study from a database. These datasets corresponded in duration (maximum 35 minutes) and presentation mode (monoscopic monitor). This comparison allows a more precise understanding of the presence experience in MaxWhere VR.

### **4.2.1 IPQ database**

The presence results of the MaxWhere VR were compared with the online IPQ dataset [2]. The online data was used if it was obtained with a mono monitor and the subjects were nonclinical. Thus, two studies were selected, but the names of these virtual environments were not included in the description. In the dissertation, these are referred to as IPQ1 and IPQ2 studies.

The duration of the virtual experience was up to 35 minutes in each case. The longer sessions were excluded from further analysis. There were no statistically significant differences between MaxWhere (M=15.7 min, SD=6.7), IPQ1 (M=18.6 min, SD=8.3), and IPQ2 (M=15.95 min, SD=6.2) mean duration as determined by one-way ANOVA ( $F(2, 59)=0.696, p=0.503$ ).

## 4.2.2 Descriptive statistics

In the analysis, I have compared the presence scores in the MaxWhere virtual reality to the presence scores of the IPQ1 and IPQ2 studies. Descriptive analyses were performed on the variables in the three groups. Results are displayed in Table 4.1.

The reliability analysis of the MaxWhere data showed that all subscales of the IPQ had high reliability. All Cronbach's  $\alpha$  coefficients for the subscales of the IPQ questionnaire were above 0.7 (spatial presence: 0.872, involvement: 0.729, experienced realism: 0.716).

**Table 4.1:** Means and standard deviations of the measured variables in the three compared studies: MaxWhere, IPQ1, and IPQ2.

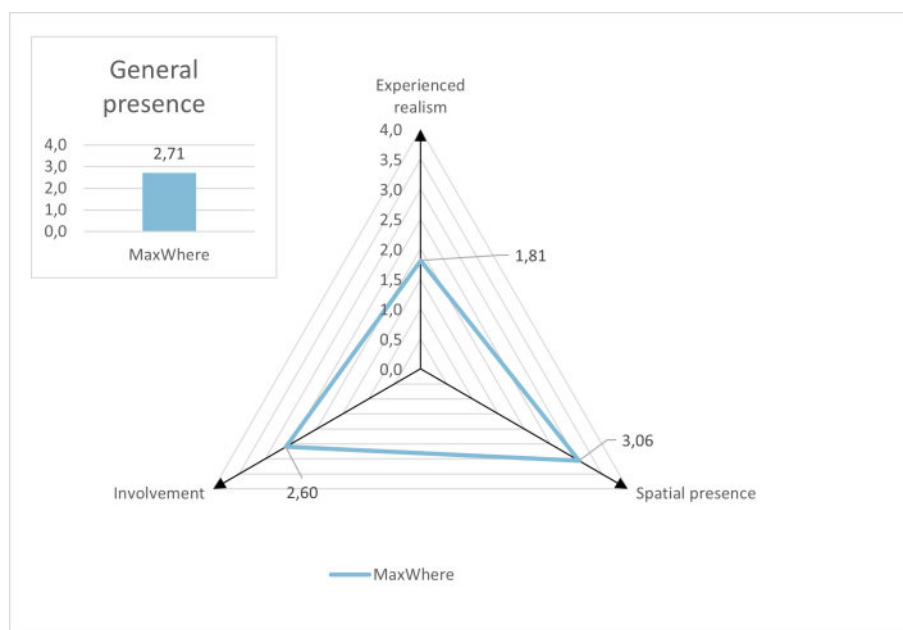
	MaxWhere	IPQ1	IPQ2
<b>Age of participants (years)</b>	20.52 ± 3.46	22.5 ± 6.03	22.05 ± 5.77
<b>VR session length (min.)</b>	15.73 ± 6.74	18.6 ± 8.3	15.95 ± 6.2
<b>General presence<sup>1</sup></b>	2.71 ± 1.77	3.6 ± 2.07	2.19 ± 1.57
<b>Spatial presence<sup>1</sup></b>	3.06 ± 1.29	2.98 ± 1.12	2.48 ± 1.07
<b>Involvement<sup>1</sup></b>	2.6 ± 1.29	2.75 ± 0.75	2.75 ± 1.24
<b>Realism<sup>1</sup></b>	1.81 ± 1.05	1.6 ± 0.54	2.1 ± 0.97

<sup>1</sup> The general presence, spatial presence, involvement, and realism, were rated on a 7-point Likert scale from 0 (not at all) to 6 (very much).

### 4.2.3 Presence profile of the MaxWhere virtual reality

The presence profile shows the strengths and weaknesses of a VR, and it can provide an overview of the ratio of the different presence components. The presence profile of MaxWhere virtual reality (Fig. 4.2, plotted from the scores from Table 4.1) shows that the spatial presence score was the highest among the subscales. That means that the users had a relatively higher sense of being physically present in the VR. On the other hand, the experienced realism factor was the lowest (i.e., the users did not rate the VR very realistic).

Vividness and interactivity, are two essential dimensions according to Steuer [140]. The vividness of the MaxWhere virtual reality is based on the visual design as it is a desktop VR. The colors are bright, and the different virtual spaces are designed carefully according to their goals. The learning spaces have a pure and clean design to help students



**Figure 4.2:** Presence profile of the MaxWhere virtual reality. The components (General presence, Spatial presence, Involvement, and Experienced realism) were measured on a 7-point Likert scale, rated from 0 (not at all) to 6 (very much).



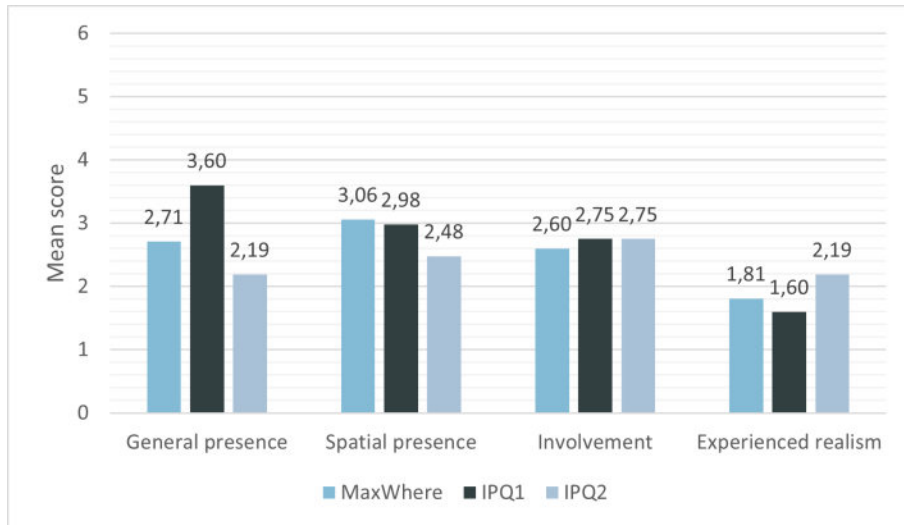
focus on the learning materials. The exhibition spaces either create a muted background for the exhibited object or create an ambient that relates to the exhibition's theme.

Interactivity has a more enhanced role in this virtual reality. The users can freely navigate in the virtual space, using the CogiNav technology [13]. They have control over the smartboards to load any web content, video, image, or document. Also, several web applications are supported that provide interactivity. In some of the MaxWhere virtual spaces, there is a control panel that allows users to change all the content of smartboards. For example, they can reach the next chapter in a learning material this way.

#### **4.2.4 Comparing the presence scores of MaxWhere and IPQ database**

In order to compare the mean IPQ scores of MaxWhere and the corresponding data of the two selected studies of the IPQ dataset, a one-way analysis of variance (ANOVA) was performed. One-way ANOVA is a parametric test that compares the mean of two or more independent groups to determine whether there is statistical evidence that the associated population means are significantly different. No statistically significant difference was found between the three studies in terms of general presence ( $F(2, 59)=2.192, p=0.121$ ), spatial presence ( $F(2, 59)=1.557, p=0.219$ ), involvement ( $F(2, 59)=0.125, p=0.883$ ), or experienced realism ( $F(2, 59)=1.556, p=0.219$ ). The means and standard deviations of each group are presented in Table 4.1.

These results mean that the MaxWhere desktop VR provides a similar level of immersion to the other two desktop virtual realities in this given time range (VR session was up to 35 minutes in each case). The scores on the different IPQ subscales of the two groups are shown in Fig. 4.3.



**Figure 4.3:** Presence components in the three studies. The components were measured on a 7-point Likert scale; rated from 0 (not at all) to 6 (very much).

## 4.3 Role of prior experience

Based on prior MaxWhere VR usage, the participants of the experiment could be divided into two groups: novices and experienced users. Novices are those who have less than one hour of experience. Those who have at least one hour of prior experience with the MaxWhere VR were considered experienced in this research.

### 4.3.1 Descriptive statistics

Nineteen people were in the novice group and twelve were in the experienced group. Means and standard deviations for the navigation experience scale and the IPQ subscales in the two groups are presented in Table 4.2. To compare the mean of variables between the two groups independent sample t-test or Mann-Whitney U test was used.

**Table 4.2:** Descriptive statistics of results on the Igroup Presence Questionnaire and the subjective navigational experience scale in the novice and experienced group.

	<b>Novice<sup>1</sup></b>	<b>Experienced<sup>2</sup></b>
<b>Navigational experience<sup>3</sup></b>	6.64 ± 2.44	7.67 ± 1.53
<b>General presence<sup>4</sup></b>	2.4 ± 1.5	3.2 ± 2.0
<b>Spatial presence<sup>4</sup></b>	2.67 ± 1.06	3.67 ± 1.34
<b>Involvement<sup>4</sup></b>	2.45 ± 1.3	2.83 ± 1.2
<b>Realism<sup>4</sup></b>	1.5 ± 0.9	2.32 ± 1.04

<sup>1</sup> Novice: None, or less than one hour of experience with MaxWhere VR prior to the experiment.

<sup>2</sup> Experienced: At least one hour of experience with the MaxWhere virtual reality.

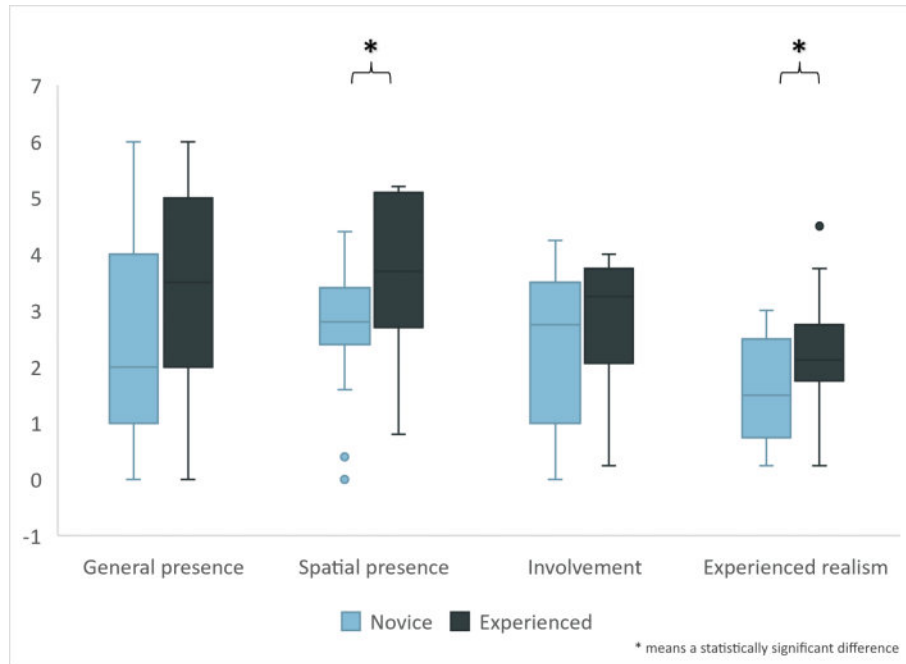
<sup>3</sup> Navigational experience was measured on a 10-point Likert scale.

<sup>4</sup> The general presence, spatial presence, involvement, and realism, were rated on a 7-point Likert scale from 0 (not at all) to 6 (very much).

### 4.3.2 Results of the statistical analysis

The navigational experience score in the novice group was 6.64 and 7.67 in the experienced group. However, according to the results of the independent sample t-test ( $t(29)=-1.26$ ,  $p=0.217$ ), the navigational experience did not differ statistically between the two groups. Ergo, the differences in the sense of presence cannot be explained by their different navigational experience.

An independent sample t-test indicated that the scores did not differ significantly between the novice (2.4) and the experienced (3.2) group ( $t(29)=-1.37$ ,  $p=0.182$ ). According to the Mann-Whitney U test ( $U=92.5$ ,  $p=0.392$ ), the involvement scores did not differ in the two groups (novice: 2.447, experienced: 2.833). The level of general presence and involvement were similar in the two groups. The latter means the attention devoted to the environment.



**Figure 4.4:** Scores of presence factors among novice and experienced MaxWhere users.

The mean score of spatial presence in the novice group was 2.67 and 3.67 in the experienced group. Based on the results of the two-sample t-test, this is a statistically significant difference ( $t(29)=-2.21$ ,  $p=0.035$ ).

The experienced users indicated significantly higher experienced realism (2.323) than the novice group (1.5), based on an independent sample t-test. ( $t(29)=-2.23$ ,  $p=0.034$ ). A box plot summarizes the mean scores of IPQ subscales in the novice and experienced groups (Fig. 4.4). Hence, novice users experienced less spatial presence than those who had at least one hour of prior experience with the software. Furthermore, they rated the virtual environment less realistic than the more experienced participants.

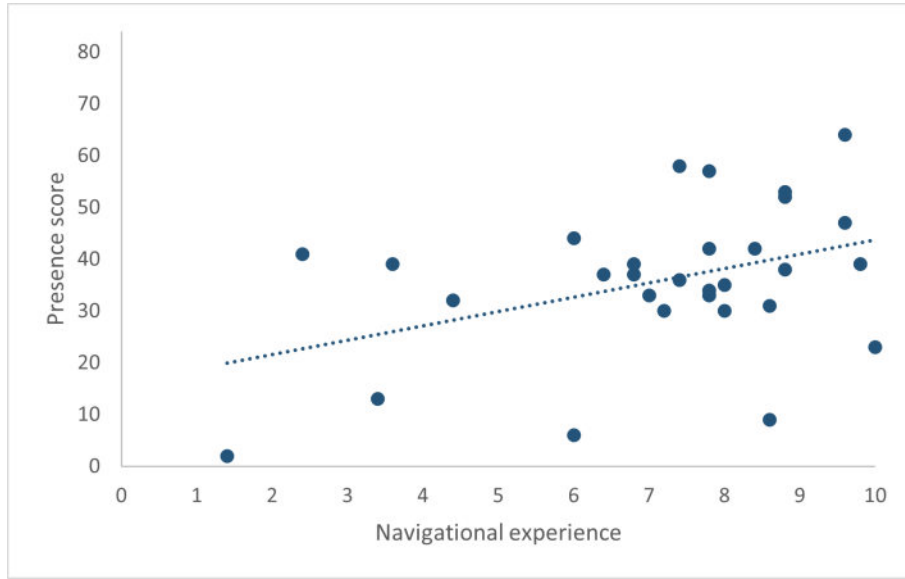
### 4.3.3 Prior experience and the sense of presence

The statistical analysis results showed that the general sense of presence in virtual reality and the involvement scores did not differ significantly in the two groups. The general presence was measured by the item ‘In the computer-generated world, I had a

sense of ‘being there’’. Furthermore, the involvement scores were similar, which shows that all participants were similarly attentive and interested in the virtual reality task.

At the same time, the mean scores of spatial presence and experienced realism were significantly higher among the experienced users than novice participants. Novice users experienced less spatial presence compared to the results of the more experienced user group. In an early virtual reality study, navigation ability was the main difference between novice and experienced users [63]. However, there was no statistically significant difference in the users’ perceived navigational performance in the two groups in this experiment. Although, this study misses the behavioral results or any objective measures of navigational performance. Thus, it is possible that the more experienced users were more effective in the interaction with the virtual environment, but the navigational experience scale could not detect these differences. For example, novice users rate the navigation as effective if they could navigate to a specific place. However, a more experienced user rated the navigation effective if he or she could arrive at the selected smartboard with a double click without “walking” through the room.

Novice users rated the virtual environment as less realistic than more experienced users’ evaluation. Prior rating of the same virtual reality sensitizes observers to the different features and characteristics of the medium, which could result in different presence scores [54]. A similar process could result that the more experienced users rated the virtual reality more realistic: with the repeated use of the software, they were sensitized and valued the different features of the virtual environment. Moreover, novice users of the VR could genuinely compare the virtual experience with reality, while the experienced participants could unconsciously consider their prior experiences with the VR.



**Figure 4.5:** Relationship between spatial presence and navigational experience.

## 4.4 Presence and the subjective navigational experience

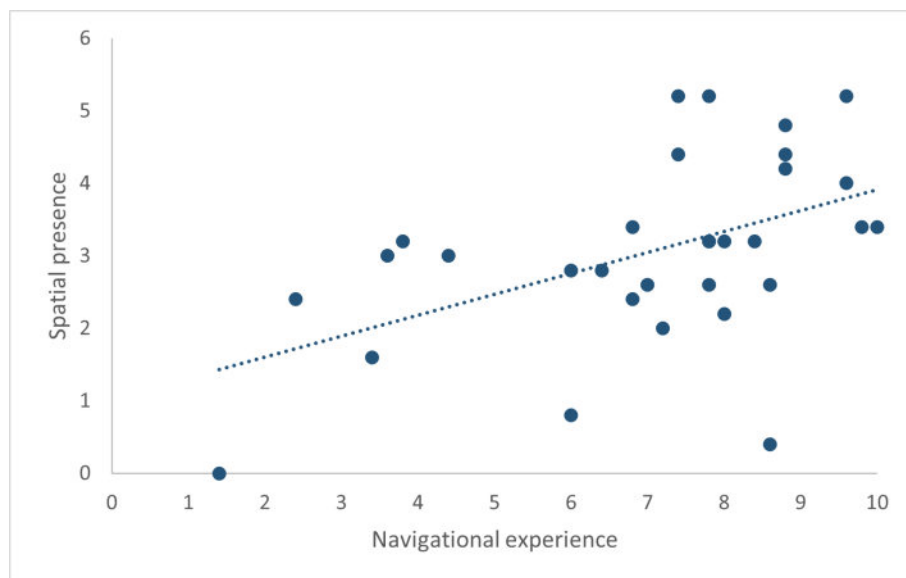
As earlier studies showed that the controller naturalness positively predicted the spatial presence [134], I have analyzed the relationship between presence and the navigational experience (that closely relates to the controller naturalness). Means and standard deviations for the IPQ subscales are presented in the first column of Table 4.1. The mean score of the navigational experience was 7.04 (SD=2.19) on a ten-point Likert scale. Pearson’s correlation was used to examine the relationship between the subjective navigational experience and the presence scores. There was a statistically significant, positive correlation between the navigational experience and presence scores,  $r(29)=0.419$ ,  $p=0.019$  (Fig. 4.5). There was also a statistically significant positive correlation between the navigational experience score and the score of the spatial presence subscale,  $r(29)=0.497$ ,  $p=0.004$  (Fig. 4.6).

Overall, there was a positive correlation between the navigational experience and presence or spatial presence. Increases in the navigation experience score correlated with

increases in the presence and spatial presence rating. In other words, those who rated the navigational experience as more automatic and natural experienced a higher sense of spatial presence in the virtual environment. This result corresponds to the previously mentioned study of Skalski and colleagues [134], which showed that the perceived controller naturalness and the naturally mapped interface require less effort to control the navigation in virtual reality and allows the users to experience it as a reality where they can be present.

## 4.5 New scientific results

The level of presence in MaxWhere virtual reality corresponds to the average presence level in other desktop virtual realities. The analysis of the presence profile has shown that the general sense of presence and spatial presence are relatively high in this VR. However, the experienced realism scale is the lowest because this VR is not designed for having high fidelity but for fostering working and learning inside virtual reality.



**Figure 4.6:** Relationship between spatial presence and navigational experience.

The sense of spatial presence in MaxWhere virtual reality positively correlated with the navigational experience. Namely, those participants who rated their navigation more automatic and natural experienced a higher sense of spatial presence. The other significant result of this study is the difference between novice and expert users. The more experienced users reported a higher sense of presence and gave a higher rating on experienced realism. Nevertheless, both the involvement and the general sense of presence were similar, which is advantageous in education, as the presence is positively related to the learning outcome.

**Thesis 2.** I have demonstrated by a cognitive psychological measurement that the sense of presence and spatial presence positively correlates with the subjective navigational experience in desktop virtual reality.

References: [21, 22, 24] ▪



## 5. Thesis 3.

### Highlighting visual information in virtual reality

**Thesis 3.** I have demonstrated by a cognitive psychological experiment that if an image is pulled out from its context and both the text and the image are pasted into a 3D digital environment, users reading text in the 3D environment will better remember the image's content. However, the same effect has not been demonstrated using a classic 2D browser. References: [15, 16, 23] ▪

Memory performance is an important segment of human cognition. In this chapter (and also in the following Chapter 6), I'm presenting my research results regarding human memory. During this research, I have used advertisements as the "target images" of the memory task to increase the experiment's ecological validity. The theoretical groundings were presented in Section 2.7 and 2.8. In Subsection 2.8.1 an introduction to web-based advertisements were presented and in Subsection 2.8.2 the relevant literature of virtual reality advertising was showed.

In this chapter, Section 5.1 presents the exact details of the experiment, such as the virtual environment, participants, and experimental procedure. Section 5.2 shows the results of this VR experiment. The VR-based study was completed by a comparison with 2D browser, which details are in Section 5.3 and its results are in Section 5.4. The last section summarises the new scientific results (Section 5.5).

## 5.1 Details of the virtual reality-based experiment

This study aimed to examine human memory performance in a 3D virtual space. In order to increase ecological validity, instead of a laboratory memory test, I have used a real-life situation with incidental encoding (reading online articles and later asking about the advertisements). I hypothesize that participants' memory performance will be better for target images displayed directly in the 3D virtual environment. To test this, I have inserted the same advertisement directly in a 3D VR space and into articles as classic banner ads. Banner ads were used because among different online advertising methods; these were the most positively rated [36].

Furthermore, to avoid the repetition effect, a between-subjects design was used, i.e., the participants were divided into two groups, one completed the task with the advertisement placed directly in the 3D space and no advertisement in the articles (VR group); the second group saw the memory test as banner ads inside the web pages with the articles (classic web-based group). Both groups completed the task in the MaxWhere VR. Thus the supposed difference between the groups is not due to the novelty of the software. By excluding the novelty effect, I could compare the memory performance in the case of a webpage banner ad and an advertisement inserted directly in the 3D virtual world. According to my hypothesis, more participants are going to remember the advertisement from the VR group than from the classic web-based group because attention and a stronger sense of presence results in better memory [101]. The VR group could benefit from this effect, as the advertisement is inserted directly into the virtual space where they experience the feeling of presence and not inserted into another webpage, which is inserted into the VR.

### 5.1.1 Virtual environment

For the experiment, the CogInfoCom17 space of MaxWhere (1.4.x version) (artist: G. Kovács; FIEK program at SZIU) was used, which is a special version of the Lecture Space



**Figure 5.1:** The virtual reality of the study (screenshot of the CogInfoCom17 space of MaxWhere [3] VR).

SZIU. This space was designed for lectures, homework, and presentations. The experiment took place in the central area, the original personal corner, and the information desk that displayed the contents of the experiment.

There is a table with five smartboards in the central part of this space. The four articles were displayed here, and on the fifth smartboard, the VR group could see the advertisement (but they do not see it in the articles; Fig. 5.2). In contrast, the participants in the classic web-based group could see only the blue pattern of the table (Fig. 5.3).

These layouts were given to the individuals as pack files, which is the archive file exporting format of the MaxWhere environment. This pack file contained the copies or references of the pinned content and the appropriate positions in the 3D space (details in Subsection 2.11.3).

### 5.1.2 Subjects

Twenty-two healthy participants aged between 19 and 28 ( $M = 23,45$  years,  $SD:2,26$ ; 18 male, 4 females) completed the experimental task. The whole experiment was conducted in Hungarian, and all the volunteering subjects were native Hungarian speakers.



**Figure 5.2:** Experimental outline for the VR-highlighted group: advertisement on the central smartboard and four articles around.



**Figure 5.3:** Experimental outline for the VR-embedded group: four articles, each with the advertisement, and the fifth smartboard is left blank.

All individuals knew the MaxWhere software, and they have not reported any problems with its usage. For the experiment, a between-subjects design was used. Thus ten individuals saw the image as a webpage banner ad, and twelve participants saw it directly in the VR space.

### 5.1.3 Procedure of the experiment

A between-subjects experimental design was applied to compare the participants' results in different groups. Individuals were randomly assigned to one of the two conditions (classic web-based or VR advertisement). The web-based advertisement group saw four online articles in the central area of the virtual space. All articles contained a banner ad on the right side of the page. The same advertisement on all four sites (Fig. 5.3). In the two conditions, the total size of advertisements was equaled.

The individuals in the VR advertisement group saw the same four articles with the same spatial layout but without the banner ads. For this group, the advertisement was displayed on a separate webtable, among the four articles (Fig. 5.2).

During the experiment, the participants filled out an online questionnaire placed in the MaxWhere VR space (Fig. 5.4). This questionnaire was the same for every individual regardless of the experimental group. The questionnaire contained all the instructions to fulfill the experiment. First, they read a short description of the whole task (without any references to the aim of the study), and with a click, they indicated their willingness to participate in the study. Then they had to answer general questions about the four articles displayed in the central area. Then they had to import another pack. With this pack, all previous contents (except for the questionnaire) were replaced with an image of a cat. The aim of this was to ensure that the participants could not see the articles or the advertisement during the following part of the study. For checking whether the participants made this import, the next question was about the image. Then they were asked if they remembered any advertisement in the virtual space. If they answered yes, they were asked to write as many details as possible about the advertisement (such as brand, product, colors, and slogan). Finally, they answered some basic demographical questions.

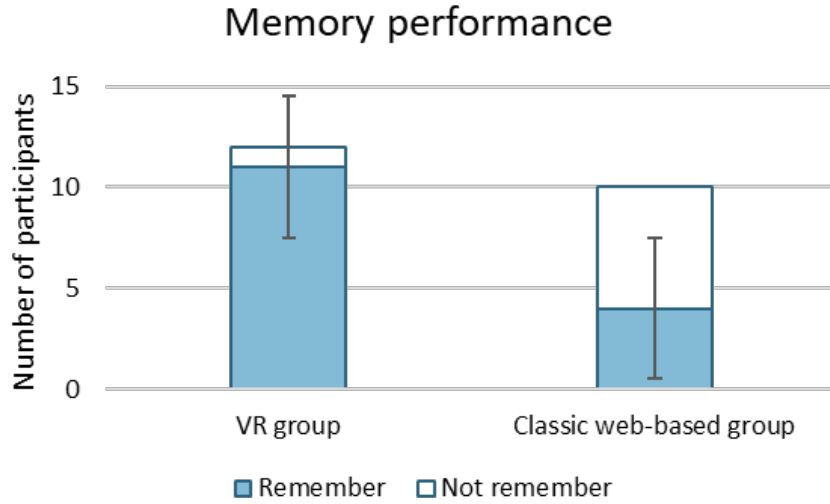


**Figure 5.4:** Online questionnaire inserted in the virtual environment for all participants.

## 5.2 Results of the virtual reality-based experiment

The goal of this experiment was to compare the effectiveness of advertisements placed directly or indirectly in a 3D virtual space. The advertisement's effectiveness was defined as the memory performance of the individuals in a free recall test. The first part of the analysis verified the individual's answers to the articles. To filter out the random completions, especially those who may not read the articles, the data of those participants who gave wrong answers were excluded from further analysis. Accordingly, 22 individuals' results are presented from the original 27 participants.

The hypothesis was that more participants from the VR group would recall the advertisement (who have seen it in the VR space and not in the articles). The Fisher's Exact Test was used to compare the memory performance of the two groups. The test's null hypothesis was that the proportion of the remembering participants in the two groups is equal. At the cut point of 0.05, the aim was to test whether any observed difference in the proportions was significant. The results indicated a significant difference in memory performance between the two groups. The prevalence of remembering participants was 91.67% (11 participants out of 12) in the VR group. At the same time, it was 40% (4 out



**Figure 5.5:** Proportion of the remembering participants between the two virtual reality groups, error bars represent the standard error.

of 10 participants) in the classic web-based group ( $p=0.02$ ). This result means that the null hypothesis can be rejected and assume that the proportion of the individuals who remember the advertisement is different in the two groups (Fig. 5.5).

The free recall test revealed that if an individual remembered the advertisement, mostly they could recall the promoted product and the brand. They also tried to recall the colors of the advertisement, but mainly they attributed the brand’s color to the product. In this comparison, there was no statistically significant difference between the performance of the VR-based and web-based groups (Table 5.1).

**Table 5.1:** Results of the free recall and the corresponding p-value of the Fisher’s Exact Test for the remembering participants of both groups.

	VR-highlight group (N=11)	VR-embedded group (N=4)	Fisher’s Exact Test (p)
Product	10	4	1
Brand	9	3	1
Colors of the ad	4	0	0.2747
Color of product	0	0	1
Slogan	1	0	1

## 5.3 Details of the comparison with 2D browser

The previously presented results were extended with a comparison to browsers. This comparison aimed to measure whether this information highlighting effect occurs in a 2D browser in a similar way as in desktop virtual reality. Alternatively, the previously presented result (more participants remembered highlighted images) is a characteristic of 3D virtual spaces. Another goal is to compare 3D highlighting and the widely used 2D embedding method.

### 5.3.1 Procedure of the comparative study

This study used the same articles and target images as the study presented in Section 5.1, but these were opened in a traditional browser on different tabs. The participants were randomly divided into two groups. The first group could have seen the ad as a banner advertisement next to all four articles embedded into the article. The members of the other group have seen one large advertisement on a different tab (the size of this one was equal to the four banner ads). This condition corresponds to the directly inserted advertisement in virtual reality. They had to answer the same questions about the articles. As in the VR study, the participants had to close the tabs of the articles, and they had to answer whether they had seen any advertisements while answering the questions. Then, if they remembered, they had to describe the advertisement precisely.

### 5.3.2 Subjects

Four groups were compared in this study, two browser groups and two from the previously presented study (Section 5.1). Altogether in the experiments, fifty individuals attended. The inclusion criteria for the final analysis was to answer the questions about the articles correctly. Thus, in the final analysis, 39 people were involved (mean age: 24,7 years, 12 women). The number of participants in each group is displayed in Table 5.2.



**Table 5.2:** Number of participants in the four experimental groups.

	Browser	Virtual reality
Embedded	8	10
Highlighted	9	12

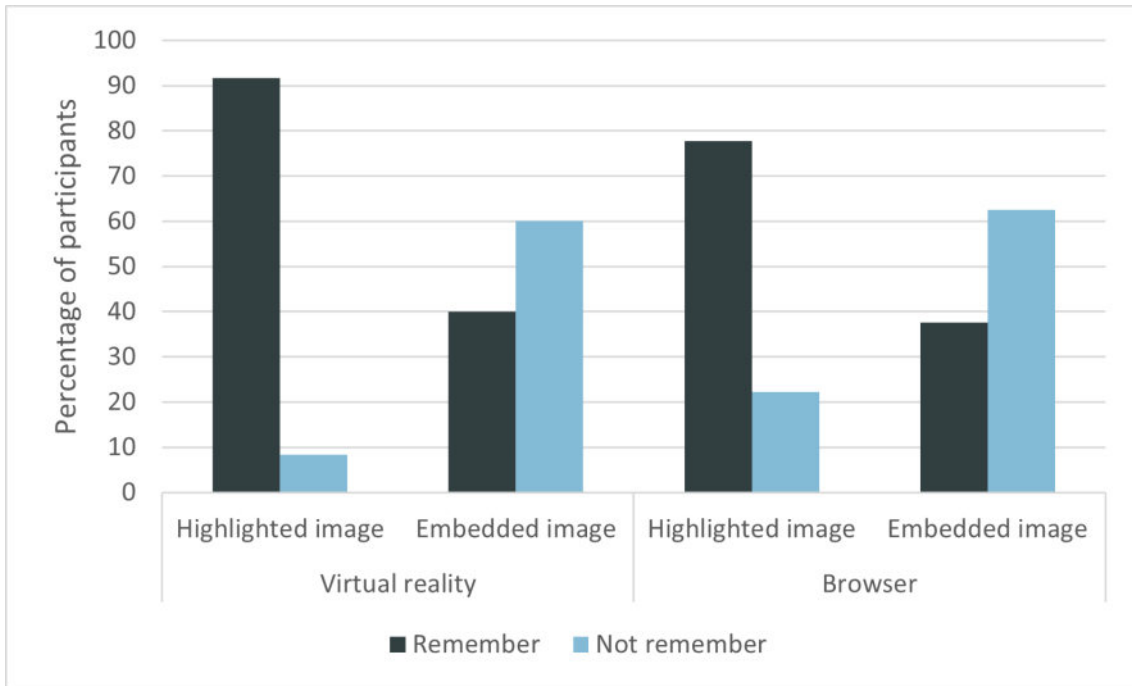
## 5.4 Results of the browser-VR comparison

### 5.4.1 Highlight information in 2D browser

To examine the effect of highlighting information, I have compared the proportion of participants who remembered the target image (advertisement) between the two browser groups: those who saw the target image embedded in a browser and those who saw it highlighted the target image in a browser. For this, Fisher's exact test was used. The advantage of this non-parametric statistical significance test is that it is not sensitive to sample size. The null hypothesis is that the proportion of the remembering participants is the same in the two groups. Based on the statistical test results, there was no significant difference in the proportion of memory between the two groups ( $p=0.153$ ). The proportion of remembering participants was 77.8% (7/9) in the highlighted image group and 37.5% (3/8) in the embedded image group. Thus, although more people remembered when the picture was highlighted, this was not a statistically significant difference. In comparison, in the virtual reality-based highlighted and embedded group, there was a statistically significant difference (Fig. 5.6). Altogether, the results measured in virtual reality could not be reproduced, but also appeared a tendency in the ratio of remembering people to the highlighted image.

### 5.4.2 VR highlight vs. embedding in browser

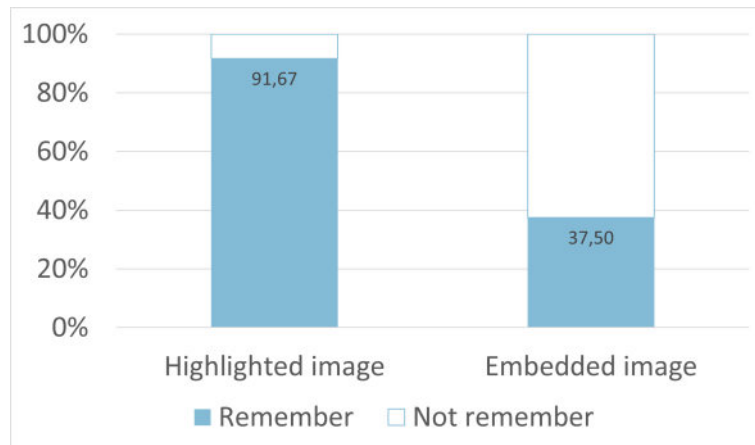
A significant advantage of virtual reality is that digital objects, such as images can be inserted directly into the virtual environment. Thus the user can walk around them and see them from different perspectives. In contrast, in browsers, it is more common



**Figure 5.6:** Percentage of participants remembering the target image in the four groups.

to embed an image or an advertisement into a webpage. Hence, another comparison was made, reflecting on the frequent use of these technologies. The ratio of remembering participants was compared in the *VR group* with directly inserted images and the *browser group* with banner ads. The ratio of remembering participants in the *VR group* was 92%, while in the *browser group* it was 38%. Based on the results of the Fisher's Exact Test, this was a statistically significant difference (Fig. 5.7). Thus, compared to two-dimensional embedding used in everyday life, images directly inserted into 3D were remembered by more people. The reason for this difference is not the novelty effect of virtual reality, as this difference also appeared in the comparison within virtual reality. Presumably, the active coding [125] is in the background. Namely, by inserting the image directly into space, not only from one direction but also from several points of the space, the user can see it and walk around.

Images directly inserted in the virtual space are more likely to get remembered due to the active exploration and active encoding. However, when the user saw the target image



**Figure 5.7:** Percentage of participants remembering the target image. The first is the group who saw the target image highlighted in virtual reality, and the second is those who saw the image embedded in a browser.

inserted in the article, like a classic banner ad, fewer people remembered this image. This difference can be the result of the ad-avoiding behavior. Namely, users try to focus on the main content in everyday life and tend to avoid or block advertisements. Therefore, direct ads are more likely to evoke stronger memory in virtual reality.

A limitation of these results is that the experiment did not measure directly whether the novelty of the placement, the large combined area vs. fragmented small areas, or the virtual reality itself is the reason for the difference. Further measurements are needed to uncover the exact cause of the memory difference found.

## 5.5 New scientific results

Based on the statistical analysis results, the highlighting effect observed in the virtual environment occurred only at the trend level in the 2D browser. There was no statistically significant difference that the image displayed on a separate tab is better remembered than the embedded one.

The difference was statistically justified in the other comparison, where the two widely used cases were compared, namely the highlighted image in VR and the web page with

an embedded image in a 2D browser. This difference indicates that ads and images displayed on a page in browsers, which are still common today, are less remembered by people than those displayed in a virtual space alone. This comparison is also meaningful because it compares the real novelty of VR, the ability to insert directly into 3D, with the websites with embedded ads. The reason for this difference is not the novelty effect of virtual reality, as this difference also appeared in the comparison within virtual reality. Presumably, active coding is in the background, that is, by inserting it into space, not only from one direction but from several points in space, the user can see it [125].

The practical significance of the results is that 3D highlighting makes it more likely to remember key information, which can be crucial in education, for example, as classical e-learning is constantly being replaced by virtual reality-based education. Thus, in a virtual educational space, the instructor can make the most important diagrams visually continuously available, thus facilitating the acquisition of the most critical information.

**Thesis 3.** I have demonstrated by a cognitive psychological experiment that if an image is pulled out from its context and both the text and the image are pasted into a 3D digital environment, users reading text in the 3D environment will better remember the image's content. However, the same effect has not been demonstrated using a classic 2D browser.

References: [15, 16, 23] ■

## 6. Thesis 4.

### Remembering additional information presented in 3D and 2D environment

**Thesis 4.** I have demonstrated by a cognitive psychological experiment that users who perform a task on documents in a 3D environment can better remember additional information about the current state of the task and have a better overview of the status of the project than users who perform the same task on a traditional 2D interface.

References: [17, 18] ▪

This chapter presents another human memory-related measure. This experiment assessed the memory performance for supplementary information located in a virtual environment. The grounding theory of human memory was presented in Section 2.7. Section 2.9.1 gave an overview of the preliminary research focused on virtual workspace effectiveness. Section 6.1 describes the details of the methods used in this study. Section 6.2 presents the results of the experiment and finally Section 6.3 introduces my theses.

#### 6.1 Details of the experiment

Desktop virtual reality can meet the requirements of an effective virtual workspace, mentioned in Section 2.9.1. It enables the user to stay in the workflow by directly manip-

ulating different types of information. For example, the 3D layout can provide insights into documents that are not in focus, but due to the perspective, they appear in the visual field. Can this kind of extra information provide further benefits to the user? Do they remember supplementary information displayed in their visual field?

A between-subjects design was used to investigate this question. Either group worked with a desktop VR and the other with a basic web browser. The experimental task required using three web pages with different content. Three web pages are quite a limited number as in most cases, much more document is used simultaneously. However, this experiment wants to measure the differences in a more straightforward task with few documents. The first one was a simple web page that contained numerical tasks. The participants had to write the result in a spreadsheet (second document). The third was an interactive figure which showed the percentage of the solved and the remaining tasks.

For the VR group, these three web pages were displayed next to each other on three smartboards. For the web browser group, these were displayed on three different tabs. The participants had to solve these numerical tasks for five minutes then they had to fill out a questionnaire. One of the questions was to estimate their performance as the percentage of the completed and uncompleted tasks. However, they could do the estimation only based on the figure, as the number of all tasks was not mentioned anywhere. Thus the use of extra information could also be measured, besides the actual performance.

### **6.1.1 Technical details of devices and software**

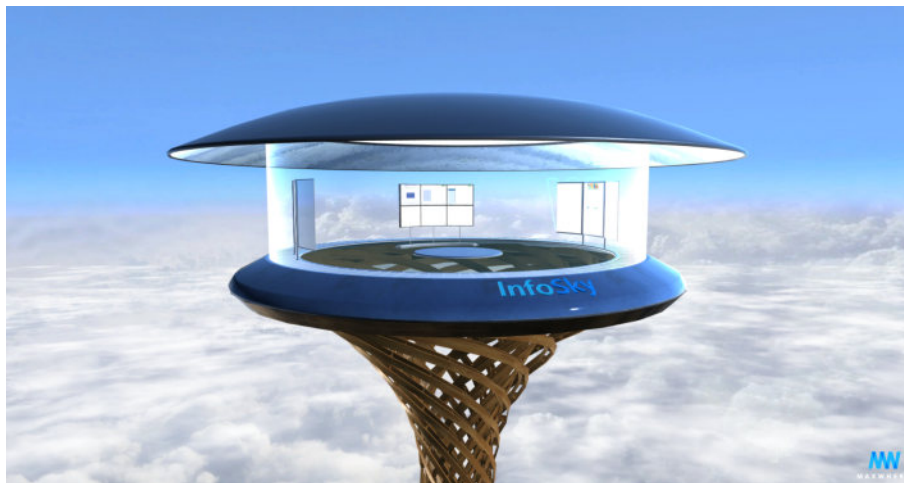
All participants completed the experiment on the same 14" laptop (LenovoYoga, 1920 x 1080px full HD display, 8 GB system memory, Nvidia GeForce 940 MX). In addition, all users used a computer mouse as a pointing device. All these features matched the system requirements of both used software.

In this study, the InfoSky space of MaxWhere (version 2.0.0-b19) was used (artist: Tanaka, 3D modeling team), which is a relatively small space with twelve smartboards (Fig. 6.1). The three web pages of the experiment were displayed on the top row of a 2x3

smartboard matrix, in the same order as the tabs were in the browser (tasks, graph, and spreadsheet). On the other side of the virtual space, the informed consent was on an A4 smartboard.

The Tutorial – HUN virtual space (artist: MaxWhere Team, MaxWhere) was also used if somebody first met this software or recorded a need to practice the navigation or the general use. This virtual environment contains a tutorial on navigation and the use of smartboards.

As a classic 2D browser, the 67.0.3396.99 version of Google Chrome [1] was used in the control group and for filling out the final questionnaire. Google Chrome was chosen because it was the most used desktop browser in Hungary [139].



**Figure 6.1:** The InfoSky virtual space of MaxWhere virtual reality.

## 6.1.2 Subjects

From the original 58 participants, 53 individuals' (32 male, 21 female; mean age 25.2 years, SD: 5.0) data was analyzed. The other five subjects had to be excluded due to technical problems or misunderstandings of the experimental task. All participants participated voluntarily. The participants were native Hungarian speakers, and all parts of the experiment were in Hungarian. A between-subjects experimental design was used

to compare the user performance in the MaxWhere 3D desktop VR environment (N=26) and a widely used web browser: Google Chrome (N=27).

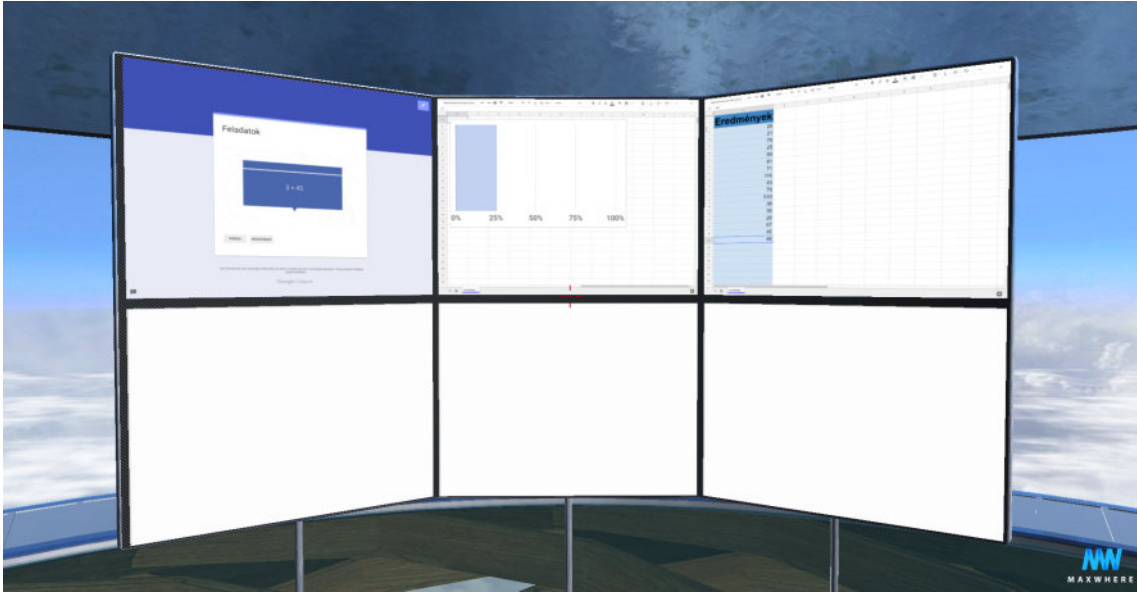
### 6.1.3 Experimental task

The participants had to complete mathematical tasks for five minutes during the first part of the experiment and record the results. The task consisted of three web pages (Fig. 6.2), the first contained the task, the second was a graph about the actual progress (percentages), and the third was an online spreadsheet where they had to write the solutions. The mathematical tasks (e.g.,  $13 + 12$ ,  $91 + 7$ ) were presented one by one, and with a click, they could display the next one. The tasks were not numbered, and they had to write them in the same column under one another on the spreadsheet. The graph showed their progress; each task was 1.5% as there were 69 tasks to minimize the probability of reaching 100% in five minutes.

The difference between the two groups was that the control group got the three web pages as three tabs of one browser window, and the participants in the experimental group saw them next to each other in a 3D virtual space (Fig. 6.2). The members of the control group (27) could change the order and layout of the three tabs. Most people (23) changed the tabs with a click, two participants alternated the windows with the alt + tab keys, and two individuals used a shared window (for the task and the results tab). The aim of letting users use their preferences was to make them work comfortably and map their preferences.

The experimental group saw the three tabs next to each other in virtual reality: on the left side was the task, on the right was the results spreadsheet, and in the middle, they could see their progress on the graph. This view was saved, and they could retrieve it anytime with the hit of the backspace.





**Figure 6.2:** Overview of the task windows for the VR group in the MaxWhere desktop VR environment.

#### 6.1.4 Procedure of the experiment

All participants were tested individually. Participants were randomly assigned to the experimental or the control group. The experimenter told them a brief explanation of the task then they read the informed consent and clicked to verify if they wanted to participate.

In the experimental group, those, who did not know before the MaxWhere VR environment, the Tutorial – HUN space (artist: MaxWhere Team, MaxWhere) was introduced to get familiar with the set-up and the navigation. They could spend as much time as needed in this virtual space, but no one spent more than five minutes there.

The experimenter explained the task and showed the appropriate web pages. The explanation also covered the meaning of the progress bar graph. Then, the participant had five minutes to solve correctly as many tasks as they could. Next, they had to fill out an online questionnaire. The online questionnaire was opened with Google Chrome in both groups. The first question was to estimate their performance (percentage), then they had to indicate which one of the followings (graph, tasks, time, results-sheet, other)

influenced their answer and rank them. Finally, they answered some basic demographic questions. Concerning the precise aim of the study (tracking and estimating their own performance), all participants were naïve.

## 6.2 Results

The objective of this study was to test the participants' memory of supplementary information in desktop VR and web-browser. During the experiment, the exact number of solved tasks, and the estimation of the percentage of solved tasks were registered. Later, all respondents' solutions were checked, and the percentage of correctly solved tasks was calculated individually.

The accuracy of the problem-solving was not included in any statistical analysis, as its individual variability does not allow to draw conclusions about the differences in the workflow between the two groups. Accordingly, the perfect solution to the numerical tasks was not expected. The accuracy of the problem-solving was 96.93% (SD: 4.36). Pearson's correlation showed no significant relationship between the accuracy of the solution of the mathematical tasks and the accuracy of the performance estimation ( $r(51)=0.084$ ,  $p=0.548$ ). Therefore, all data were included in further analysis irrespectively of the accuracy of the mathematical problem-solving.

In the control group, the participants could set the display of the three web pages. Most individuals used the mouse to change with clicks between the tabs (85.2%), the other 14.8% separated the task and the results spreadsheet in different windows. 7.4% of them alternated between the windows with the alt + tab keys, and only 7.4% used a shared display. The results of the Kruskal-Wallis test ( $\chi^2(2, N=27)=0.362$ ,  $p=0.834$ ) revealed no significant differences in the accuracy of the performance estimation between them.

### 6.2.1 Performance estimations in VR and browser

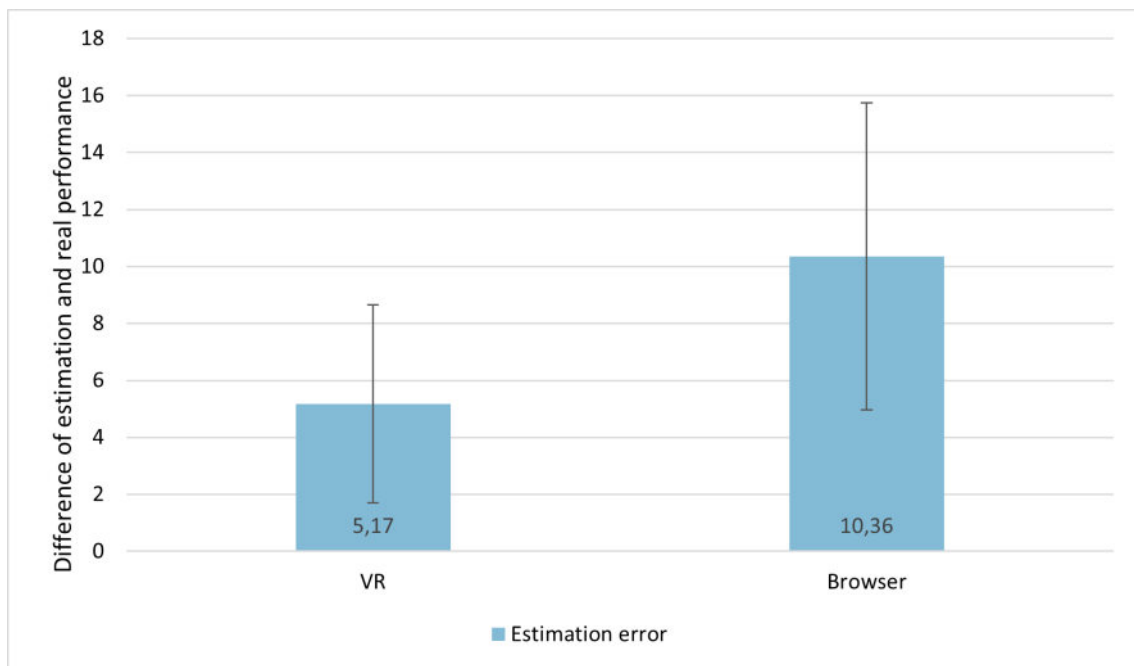
The primary dependent variable was the accuracy of performance estimation. The accuracy was calculated as the absolute difference between the actual and estimated performance. The smaller values mean more accurate estimation, which means better memory of the supplementary information.

The aim was to compare the accuracy of performance estimation between the two groups. The Shapiro-Wilk normality test showed a significant departure from the normal distribution in both groups (browser group:  $W=0.871$ ,  $p=0.003$ ; VR group:  $W=0.676$ ,  $p<0.001$ ). Thus, the Mann-Whitney test was used for the comparison. Equal variances were assumed based on Levene's test ( $W=4.02e-05$ ,  $p=0.995$ ). The independent samples Mann-Whitney rank test ( $U=300$ ,  $p=0.364$ ) showed no significant difference between the means of estimation accuracy between the two groups. This result means that a desktop VR ( $M=12.37$ ,  $SD=16.02$ ) does not facilitate a better accuracy estimation than a 2D browser ( $M=13.54$ ,  $SD=12.42$ ), even though in the VR group, all participants could see the graph constantly.

### 6.2.2 Performance estimations based on the graph

Those who did not look at the performance graph during the experiment were only guessing, not estimating. The provided graph was the only clue to estimate the individual performance correctly. As the participants did not know the number of possible tasks, the tasks were not numbered. At the start of the experiment, all participants were informed about the meaning of the progress bar. Hence, we compare those members of the two groups who indicated the graph as their primary aid to estimate their progress. Twenty-five participants' results were included in this test: 7 from the control, and 18 from the experimental group. Two independent sample t-test was used to test this. The Shapiro-Wilk normality test revealed that the accuracy of performance estimation was normally distributed for both groups (browser:  $W=0.958$ ,  $p=0.798$ ; VR:  $W=0.929$ ,

$p=0.187$ ). Levene's test assessed the homogeneity of variance ( $W=1.93$ ,  $p=0.178$ ). The two independent samples t-test indicated that the accuracy of performance estimation was significantly more accurate ( $t(23)=2.73$ ,  $p=0.012$ ) for those who completed the task in MaxWhere VR ( $M=5.17$ ,  $SD=3.47$ ) than for those who made it in 2D browser ( $M=10.36$ ,  $SD=5.39$ ). In other words, the participants in the VR group estimated their performance more accurately.



**Figure 6.3:** The error of performance estimation in the subsample of those who ranked the graph as their primary source for estimation. The smaller values mean more accurate estimation; error bars represent the standard deviation.

### 6.3 New scientific results

This study aimed to examine the benefits of seeing supplementary information in an extra window and compare this phenomenon in desktop VR and classic web-browser. The results show no significant difference between the two methods in contrast with my hypothesis. Those who completed the task in MaxWhere desktop VR did not estimate their performance better. As the instructions did not indicate that they would have to

use this information later, many participants ignored the graph and focused on the other parts of the task.

The experiment was designed to test the memory of this graph. Thus, the performance estimations were only almost random guesses without watching the graph. Therefore, the difference between those who indicated the graph as their source of estimation is much more informative. This sub-sample contained 25 people (VR: 18, browser: 7), and the statistical analysis showed a significant difference between them. Those who worked in the MaxWhere VR estimated more accurately their performance than those who used the Chrome browser for the same task. Namely, they could benefit more from supplementary information if it appeared in their visual field.

These results are in line with an already known tendency: namely the overview tendency, which means that when people work on a screen, they prefer to have the possibility to view all information simultaneously [51]. A virtual 3D environment satisfies this expectation, and users can look at all documents at once. Moreover, they can use the gained supplementary information in their ongoing projects.

**Thesis 4.** I have demonstrated by a cognitive psychological experiment that users who perform a task on documents in a 3D environment can better remember additional information about the current state of the task and have a better overview of the status of the project than users who perform the same task on a traditional 2D interface.

References: [17, 18] ▪

## 7. Applications of my research results & future research

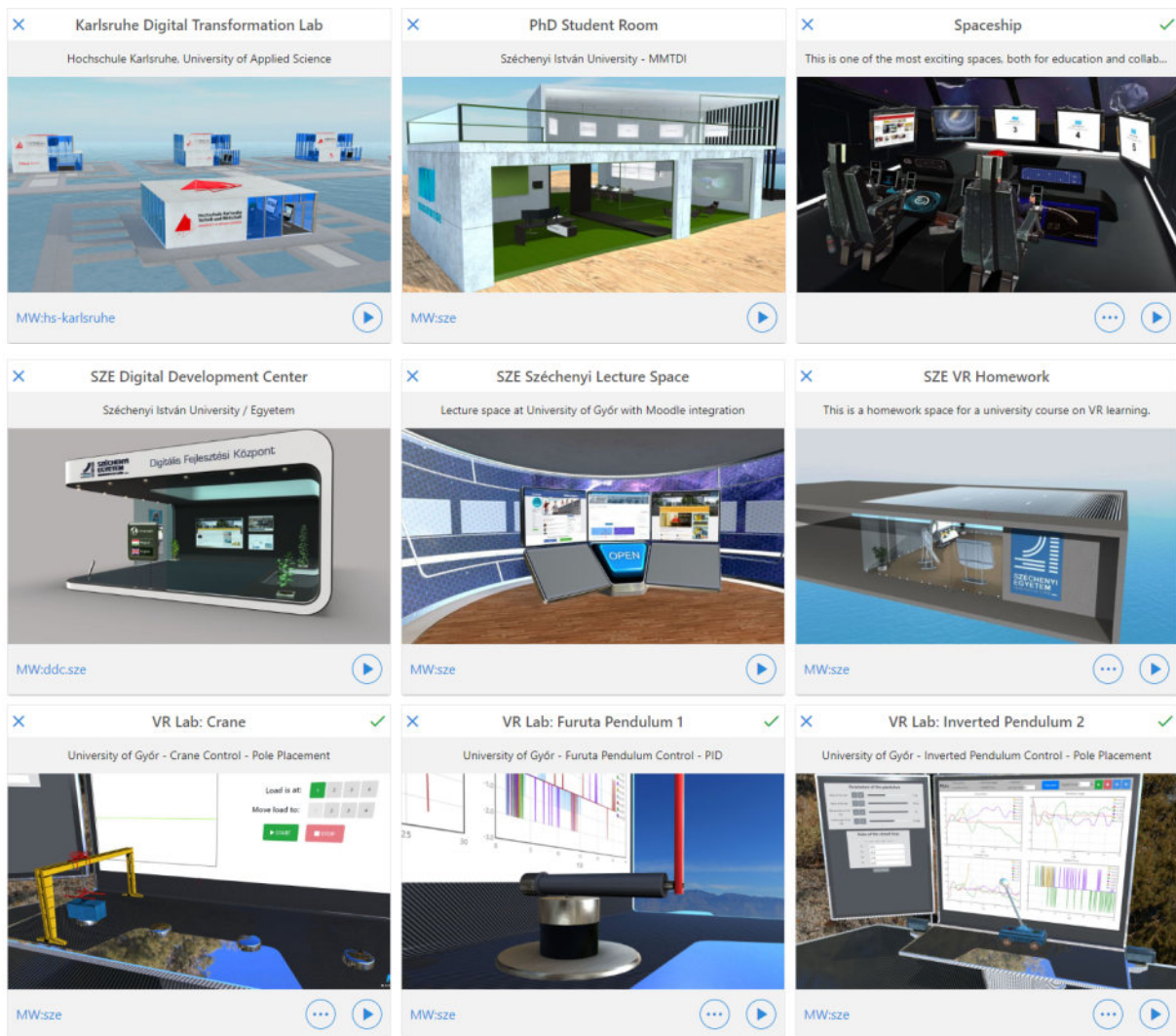
In the previous sections of the thesis, I have presented my research on virtual reality and the role of cognitive functions. The present chapter summarizes these results, presents the future research goals, and highlights the possible and the already realized applications of the presented results. In the following sections, these applications are presented in detail.

### 7.1 Education

My research results regarding the role of individual spatial abilities have proved that this desktop virtual reality is suitable for users with different levels of spatial abilities. Thesis 1 claimed that the measured individual spatial abilities such as mental rotation ability and spatial memory are not related to the successful task completion in the desktop version of MaxWhere virtual reality. Therefore, its application in educational institutions does not cause any disadvantage for learners with lower spatial abilities. Furthermore, Thesis 1 claimed that the users' navigational experience is also independent of these spatial abilities. Thus, a positive subjective navigational experience, which is one of the essential pillars of VR experiences, is accessible to all users irrespectively of their spatial abilities of these users. In education, it is fundamental to provide widely available and usable platforms that are feasible and usable for a wide range of students. My research

results regarding the role of individual spatial abilities claim that this desktop virtual reality could be a suitable educational platform (Fig. 7.1).

Previous studies [116, 117, 132] showed positive relation between the sense of presence and human performance, or learning outcome. Therefore, in educational virtual realities, it is beneficial to help students experience presence during their learning session in the 3D space. Thesis 2 claimed that presence positively correlated with the subjective navigational experience. Thus, it is recommended to help the users of educational VRs to practice navigation, as with a smooth navigational experience, it is more likely that



**Figure 7.1:** Different educational spaces available in the MaxWhere virtual reality.

they experience a higher level of sense of presence, which could also be beneficial for their learning outcome.

Thesis 3 and 4 focused on human memory, that is essentially connected to learning and education. Thesis 3 proved that an image is more likely to be remembered when it is separated from its original 2D context and inserted directly into the 3D space. This result can be easily applied in educational virtual spaces, as any visual information or figure can be saved as an image file and inserted into a separate smartboard in the MaxWhere virtual reality. This highlighting method can help the students not just by showing the most important figures of the learning materials, but it directly helping them to memorize the figure. Furthermore, the results summarized in thesis 4 showed that even when these images are not in the focus of the task, the users of virtual reality are more likely to remember than those who used a 2D interface for the same task.

## **7.2 Educational spaces at the Aptitude Testing, Skills Development, and Training Center**

As shown above, the results of this dissertation can be applied in the field of education. In the present section, the virtual educational spaces of the Aptitude Testing, Skills Development, and Training Center are presented. During the development of these spaces, some results of this dissertation were considered.

My research proved that different individual spatial ability levels do not impede the widespread use of virtual reality. Thus, it is an appropriate tool and technology to offer e-learning content in a virtual environment. Furthermore, I have shown that highlighting an image by directly inserting it into the 3D space can help users remember it. These presented principles are already applied in the educational spaces of the Aptitude Testing, Skills Development, and Training Center in Budapest. This project aims to support human resource assessment and help the clients with specialized virtual and physical training as well. The general educational space of this project has eight smartboards for



displaying different educational content and provides the possibility to highlight and focus on visual information. The spatial layout makes this virtual room suitable for clearly structuring documents. With the help of the control panel placed in the space, much more content can be handed over to the students by allowing them to switch between the displayed contents with one click. In Fig. 7.2 the general educational space is shown with several smartboards arranged to display content.



**Figure 7.2:** General educational space with several smartboards to display the curriculum.

The same principles were applied to the other educational spaces, such as the three virtual spaces that help to learn the use of ErgoScope (Figure 7.3). ErgoScope is a high-fidelity work simulator with three panels that assess respectively static and dynamic force; holding/grasping force, touching/tactile functions, keyboard use; efficiency of use of buttons and switches, endurance/loadability, and monotony susceptibility. A 3D virtual learning space has been created for each of the three panels of ErgoScope. Each panel available in MaxWhere is an exact, lifelike copy of the original elements. Its proportions, colors, and materials correspond to reality. Taking advantage of the possibilities provided by the virtual space, videos and documents showing the operation and technical structure of the given ErgoScope panel can be accessed by placing them on smartboards. In addition to the documents for each measurement, a shorter, video-based curriculum for easier understanding is also available in the VR spaces.



**Figure 7.3:** The educational spaces for the operators of the ErgoScope work simulator. The three panels of the work simulator are the virtual model of the physical one. In each space, three smartboards were placed to display the learning content.

## 7.3 Advertising

In addition to education, the research results on information highlighting and the placement of 2D advertisements in virtual space can also be used in the advertising industry. Thesis 3 is based on a research that used advertisements to assess the memory performance of the users. The results showed that placing the 2D image-based advertisement on a different smartboard next to the content results in better memory performance. However, the same method in a 2D browser did not result in a higher rate of remembering participants. In the last year, some studies [25, 100, 149] cited this research from the field of media communication that focused directly on advertising, that shows the timeliness of this topic besides the possible application of the results in the advertising industry.

The previously mentioned result can also be applied in virtual product showcases. These are also offered on the MaxWhere platform [5]. These virtual showrooms contain a

lifelike, detailed three-dimensional model of the product, and on the smartboards, detailed descriptions, videos, and image-based advertisements can be displayed (Fig. 7.4).



**Figure 7.4:** Mollia showroom in MaxWhere virtual reality.

## 7.4 Designing virtual spaces

All the previously presented possible application closely relates to the design of virtual realities. Users of virtual reality environments can efficiently use the spaces if these are planned, designed, and realized in a manner that provides the possibilities to enhance images or smoothly navigate. Besides educational virtual realities, these principles can be applied in other types of VR spaces, such as in virtual conference rooms, exhibitions, and trade shows.

Equally important is to design the interaction and navigation with the VR environment appropriately. Because, as Thesis 2 showed, the subjective navigational experience is related to the sense of presence that is the essence of any VR experience.

## 7.5 Future research goals

This section summarizes the possible outlooks and future research. In addition to the measurement of specific spatial abilities (presented in Section 3.1.3), I plan to include assessing the perceived spatial abilities in the research, i.e., how much the person thinks that they usually cope well with spatial tasks. When people think that their spatial abilities are low, they could avoid using VR technology because they may think that it requires special spatial skills. Furthermore, I aim to measure the participants' relationship with virtual reality the technology apprehension. Technology apprehension could be defined as a fear or anxiety associated with situations that require interaction with some form of technology [72]. Examining technology apprehension among students and teachers could be interesting in the field of education, where the spread of disruptive technologies is already researched [74]. As an additional measurement, I would also examine the characteristics of first use and mastering the software.

Another future research would compare the different navigational tools, their effectiveness, and their usability in different cases. For example, the users inside MaxWhere virtual reality can navigate with a mouse, touchpad, touchscreen, or even with hand gestures [120]. These different devices could be beneficial in different cases. For example, in a virtual showroom or when the user first meets with this virtual reality, it is essential to use the easiest device to handle. The availability of devices is also essential. The external mouse or the touchpad is the most common device in educational spaces. Examining the effectiveness of these two tools in educational spaces and virtual laboratories is not just scientifically interesting, but the results could help the everyday usage of VR in education.

A further research goal would be to supplement these measurements with an eye tracker. Eye-tracking is basically a sensor technology that makes it possible to know where the participant is looking on a screen. Such a device would allow studying the movements of the users' eyes during a virtual reality session. Eye-tracking could give insight into different cognitive processes, such as the attention and focus of the person.

It could help to understand the behaviors during the VR sessions and find those parts of a virtual environment that catches the attention. This technology could also help the further development of virtual realities that foster effective learning.

## 8. Summary of new scientific results

**Thesis 1.** I have examined by a cognitive psychological measurement the relationship of individual spatial abilities (spatial memory, mental rotation) with task performance and subjective navigational experience in desktop virtual reality, and there was no statistically significant correlation between the measured variables.

*Navigational experience:* How natural and automatic the movement in virtual space is. A better navigation experience means more natural, automatic navigation.

References: [19, 20] ▪

**Thesis 2.** I have demonstrated by a cognitive psychological measurement that the sense of presence and spatial presence positively correlates with the subjective navigational experience in desktop virtual reality.

References: [21, 22, 24] ▪

**Thesis 3.** I have demonstrated by a cognitive psychological experiment that if an image is pulled out from its context and both the text and the image are pasted into a 3D digital environment, users reading text in the 3D environment will better remember the image's content. However, the same effect has not been demonstrated using a classic 2D browser.

References: [15, 16, 23] ▪

**Thesis 4.** I have demonstrated by a cognitive psychological experiment that users who perform a task on documents in a 3D environment can better remember additional information about the current state of the task and have a better overview of the status of the

project than users who perform the same task on a traditional 2D interface.

References: [17, 18]

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# Appendix

## A.1 Hungarian translation of the Igroup Presence Questionnaire

Most néhány állítást fogsz látni virtuális élményekről. Kérlek jelöld, hogy mennyiben felel meg az állítás a te mostani élményednek. A válaszok teljes skáláját használhatod. Nincsenek jó vagy rossz válaszok, csak a véleményed számít. Láthatod majd, hogy néhány kérdés nagyon hasonlít egymásra. Ez statisztikai okokból szükséges. Még egy fontos dolog: Válaszolj minden kérdésre, kizárólag a mostani élményednek megfelelően.

1. Mennyire voltál tudatában a valós környező világnak mialatt a virtuális térben navigáltál? (pl.: hangok, szoba hőmérséklete, más emberek, stb.)
2. Mennyire tűnt valóságosnak számodra a virtuális világ?
3. Úgy éreztem, hogy a virtuális térben tevékenykedek, nem pedig kívülről irányítok valamit.
4. A virtuális környezetben szerzett élményedet mennyire érzed konisztensnek a valós világban szerzett élményeiddel.
5. Mennyire tűnt valóságosnak számodra a virtuális világ?

6. Nem éreztem magam jelen a virtuális térben.
7. Nem voltam tudatában a valós környezetemnek.
8. A számítógép által létrehozott világban úgy éreztem, hogy "ott vagyok".
9. Valahogy azt éreztem, hogy a virtuális világ körülvett.
10. Úgy éreztem, jelen vagyok a virtuális térben.
11. Még így is figyeltem a valós környezetemre.
12. A virtuális világ valószerűbbnek tűnt mint az igazi világ.
13. Úgy éreztem, hogy csak képeket látok.
14. Teljesen lenyűgözött a virtuális világ.

## A.2 Subjective Navigational Experience Scale (Hungarian)

Értékeld a térben való navigációdát! Értékeld 1-től 10-ig, hogy mennyiben értesz egyet az adott állítással.

1. Magabiztosan mozogtam a térben.
2. Éreztem, hogy én kontrollálom a térben a mozgásomat.
3. Nehezen navigáltam oda, ahová szerettem volna. (*reversed scored item*)
4. A virtuális térben való navigáció automatikus volt számomra.
5. A virtuális térben való mozgást természetesnek éreztem.