Design Suggestions for Digital Workflow Oriented Desktop VR Spaces

Anna Sudár[1,2,3,*], and Ildikó Horváth[1,2,3,*]

Abstract—**This paper presents an examination of design principles for 3D Virtual Reality (VR) environments, with a focus on enhancing digital workflows. Employing objective data, the study sets out to clarify the primary design considerations for crafting effective 3D VR spaces. Through empirical research, the authors conducted comparative analyses of task performance within both classical 2D Windows and in 3D VR environmental contexts, exploring users' perceived difficulty levels alongside eye-tracking data. The findings reveal that, although 3D VR environments rich in distracting elements and demanding high navigational effort increase perceived task difficulty, these factors do not negatively impact overall performance or task completion time. Interestingly, eye-fixation duration results indicate that visual fixation in 3D VR falls within expected norms, whereas in 2D scenarios, fixation rates are significantly higher, more than doubling those observed in 3D settings. Drawing on these insights, the paper supports the design of 3D VR spaces that are simpler and intuitive, necessitating minimal navigation, thereby optimizing task performance efficiency.**

Index Terms—**virtual reality, desktop VR, virtual space design**

I. Introduction

Ergonomic considerations in Virtual Reality (VR) are crucial for ensuring a comfortable, safe, and engaging user experience and supporting performance efficiency. These considerations primarily address the physical interaction between the user and the VR environment to minimize discomfort and potential health risks. A large volume of scientific studies support the idea that user experience (UX) design is crucial, as good UX design has been shown to enhance engagement and motivation, and can help maintain user attention for longer durations compared to traditional 2D interfaces [1]–[3]. These effects also extend to 3D spaces, as they allow users to create, visualize, and recall information in visually appealing and persuasive learning environments [4], [5]. Desktop VR combines elements of traditional computer use with the immersive qualities of VR, making it essential to consider both digital ergonomics and the unique demands of a 3D virtual environment. In today's digital interface design, which is connected to task performance and knowledge acquisition, it is advisable to take into account research results based on eye-tracking technology measurements. These studies have found correlations between fixation numbers and task difficulty, and fixation durations might be influenced by underlying affective processes that contribute to learning. [6]–[9].

[1] Corvinus Institute for Advanced Studies, Corvinus University of Budapest, Hungary
[2] Institute of Data Analytics and Information Systems, Corvinus University of Budapest, Hungary
[3] Hungarian Research Network, HUN-REN, Budapest, Hungary
(*Email: {anna.sudar, ildiko.horvath}@uni-corvinus.hu)

DOI: 10.36244/ICJ.2024.5.14

The UI should be intuitive and easy to navigate. One primary consideration in designing spatial elements is to take into account human spatial perceptions. Accordingly, it is recommended to design virtual spaces as open areas or, in the case of closed spaces, with high ceilings [10]. Good quality audio that is synchronized with the visual elements of the VR environment can enhance the experience without causing auditory strain. Text and icons need to be large and clear enough to be easily readable. Interaction methods should be natural [11] and not require excessive or uncomfortable movements or complicated workflows. The ability for users to customize their VR experience (like adjusting sensitivity settings, UI elements, etc.) can greatly improve comfort and accessibility for a wide range of users. In this study, drawing from our research results, we aim to establish design guidelines aimed at enhancing user productivity and working effectiveness and contributing to the advancement of desktop VR environments. The structure of the paper is organized as follows: In the second section, the Definition and Metrics are presented. This section introduces key concepts, definitions, and the metrics used to evaluate virtual reality environments. The next section is the intersection of Cognitive Infocommunications (CogInfoCom) [12], [13] and cognitive aspects of VR (cVR) [14] technologies, presenting relevant research findings. The Research Context sets the background for understanding the framework of this study. Then, the authors present the main finding of the study including data analysis, interpretations, and the implications of research within the VR domain. The session Discussion critically examines the research results, discussing their significance, the limitations encountered, and how they relate to existing literature. Based on this research, the authors propose actionable recommendations for designing immersive and user-friendly VR environments to support performance efficiency. The paper concludes by summarizing the key findings, their implications for the field of VR, and suggesting directions for future research.

II. Definition and metrics

The objective of this chapter is to define essential terminology, providing clarity and ensuring a comprehensive understanding of the terms employed throughout the paper. Several of the key definitions presented herein have their origins in prior publications by the authors. However, it is imperative to emphasize that their application within this context is entirely novel and original.

A. Digital workflow—DW

[15] Digital workflows determine the order in which individual digital elements are to be accessed or processed during the course of a digital project. We distinguish among the following types of digital workflows:

1) 1st order (linear): The digital elements are to be accessed in a static and sequential order, one after the other.

2) 2nd order (loopy): There are loops in the order in which the digital elements are to be accessed, so that individual elements, or smaller sequences thereof, are to be accessed repetitively. Such loops can be characterized by length and number of repetitions.

3) 3rd order (networked): Digital elements accessed during the project are structured as hierarchical loops, so that the project may contain subprojects of subprojects, and/or the ordering of digital elements may be different upon different repetitions of the loops.

4) 4th order (algorithmic): It is possible that the project contains branches, so that different digital elements are accessed dynamically in an order that depends on information obtained during the project.

B. Digital Guidance—DG

[15] Digital guidance is taken to mean a process that unambiguously drives the user's attention during the digital workflow and thus reduces (partially, or to 0) the time required for searching for and finding the relevant digital content. It is possible to distinguish among three forms of digital guidance as follows:

1) none: no guidance is applicable, or the representation of the digital content doesn't involve embedded digital elements (instead, the elements are provided through separate lists).

2) sequential (DG-S): The digital elements are traversed in sequential order. It is thus possible to jump from one element to the next in the context of a digital workflow.

3) random access (DG-R - event/dynamic focus-driven): One can switch between sequences of digital elements, and thus follow non-static sequences (for example, in the case of DWs of the 4th order).

C. Information Availability—IA

[11] This indicates what percentage of the information (digital content) needed to execute a workflow is available in the digital work environment when executing up to 1 Navigation Based elementary Operation.

Remark: e.g., 100 percent, if all the information required to execute the workflow is available and can be accessed by a navigation operation.

D. Information Access Cost—IAC

[11] The weighted sum of the time spent accessing information for each type of operation, where the weights are the number of elementary operations corresponding to that type of operation.

$$IAC = \sum_{i=1}^{n} O_i * t_i \tag{1}$$

Remark: this metric is high even when complex operations are performed in the same amount of time and when simple operations are performed for a long time. This includes the complexity of the operation and the user's ability.

E. Information Validity—IV

[11] This indicates the percentage of the information presented in the digital work environment that is directly required for task execution.

IV = Number of Valid Information Units/Summa necessary information units number.

F. Personalized Workflow Order Ability—PWO

[11] This is an indicator of the facility of the digital work environment to provide users with the ability to arrange digital content in their own way. The value is 0 if the option is not provided, 1 if the users can set the layout themselves, and 2 if the optimal layout is automated with AI support.

G. Personalized Information Overview—PIO

Indicates the ability of the digital work environment to provide users with the ability to set personalized information overview. The value is 0 if the option is not given, 1 if the users can set the layout themselves, and 2 if it is automated with AI support.

H. Preference point

Preference points in the virtual space that users were more likely to visit in order to find the spots that best allowed them to oversee the space and solve their tasks.

I. Content arrangement types

Patterns with which users preferred to arrange the content

1) Content: content types that had a similar subject matter were most likely to be arranged in clusters, in close proximity to each other.

2) Type: similar content types were most likely to be arranged in clusters, close to each other.

3) Mixed: primal organizing principle is the content, but within the same area, the secondary organizing principle is the type.

III. Antecedent researches by CogInfoCom and cVR

CogInfoCom stands at the intersection of infocommunications and cognitive sciences, striving to enhance the co-evolution and interplay between human cognition and digital technology. This interdisciplinary field is dedicated to elevating human efficiency in digital workspaces and refining work processes through innovative IT solutions. It delves into the mutual evolution of infocommunication devices and human cognitive functions, aiming to optimize interaction within digital environments [12], [13], [16].

cVR, on the other hand, delves into the expansion of human cognitive abilities through the utilization of various technologies within a three-dimensional spatial framework.

Here, VR systems, as advanced infocommunication devices, play a pivotal role. They revolutionize information organization and management, allowing for spatial categorization and prioritization of data according to its significance in the workflow. VR's capacity for collaborative use and integration of other technological advancements further underscores its value in this domain [14].

CogInfoCom and the cVR field are extensively researched scientific domains, showcasing significant advancements such as the development and enhancement of the three-dimensional virtual library model [17], [18]. This model opens up new possibilities in digital information architecture. The fields also delve into 'mathability,' which investigates the synergy of artificial and natural cognitive abilities in mathematics [19], [20]. Furthermore, they are at the forefront of pioneering new educational methodologies, or foreign language education and linguistics [21], and are actively exploring learning challenges and emerging opportunities in the rehabilitation of autistic children [22], underlining their expansive and dynamic nature.

Moving to the connection with UI design, VR systems herald a paradigm shift from conventional command-based interactions to dynamic, user-centric interfaces. This shift necessitates a deep understanding of human behaviour within these virtual environments, provided by cognitive science. The inherent properties of VR, coupled with insights into human cognition, pave the way for more sophisticated and efficient virtual workspaces compared to traditional 2D interfaces. The introduction of a third dimension not only facilitates more organized information management but also resonates with the innate spatial understanding of human users. This spatial familiarity, along with the use of metaphors, contributes to a robust comprehension of tasks and data. Consequently, desktop VR systems enable collective visualization and observation, fostering an environment conducive to the sharing of knowledge and information [23].

VR brings new challenges and opportunities in the context of UI and information management. While traditional Windows interfaces offer users a familiar, structured environment controlled by mouse and keyboard, VR is a digital interface that provides interaction in a much more immersive spatial environment and operates according to a completely different paradigm. In recent years, several publications in the field of CogInfoCom and cVR have presented research results related to VR design. Of these, the relevant results for this study are:

Virtual Reality (VR) introduces a dynamic array of challenges and possibilities within the realms of User Interface (UI) design and information management. Contrasting the conventional, well-known setup of Windows interfaces, which users navigate via keyboard and mouse, VR offers a novel and immersive spatial interface operating under a fundamentally different paradigm. Recent years have seen a surge in scholarly work within Cognitive Infocommunications (CogInfoCom) and Cognitive Aspects of Virtual Reality (cVR), contributing significant insights into VR design.

Experimental research has shown that preference points and attentional focus points can be found in 3D virtual reality spaces. In three-dimensional virtual reality settings, users tend to concentrate more and spend additional time at certain points of interest, which helps them navigate and complete assigned tasks [24]. Moreover, using virtual reality interfaces has been linked to improved recall of the process involved in organizing three-dimensional objects in a given space [25], [26], and also enhances the retention of information distributed across a space [25]. Cannavò and colleagues suggest that automating the conversion from two-dimensional to three-dimensional formats can significantly enrich the user experience in virtual reality workspaces, making it more engaging and productive [27].

Berki and associates conducted a study comparing how well users remember images shown in a three-dimensional virtual reality setting as opposed to a two-dimensional website. They discovered that the virtual reality environment was more effective in aiding memory recall [28], [29]. In a similar vein, it was observed that desktop virtual reality systems outperform traditional two-dimensional browsers in memory retention of additional information [30].

In previous research conducted by one of the contributors to this study, the effectiveness of personalization based on learning styles in three-dimensional desktop virtual reality was examined. The findings from that research revealed that when the instructional content was tailored to their individual learning styles, users achieved scores that were 20 percent higher, along with an 8–10 percent improvement in response times in subsequent assessments [31]. This customization of the learning environment demonstrated a significant impact on user behaviour and performance in the 3D virtual reality context.

These studies collectively indicate that virtual reality technology may play a crucial role in reducing the mental effort required for spatial memory and in improving performance in tasks that involve spatial orientation, particularly those that involve navigating through a vast array of digital documents.

In virtual spaces, the creation of a sense of presence is of utmost importance, and it is equally crucial to bestow upon the user a feeling of control [32]–[34]. This serves several purposes. Firstly, in reality, individuals have control over their own bodies, primarily altering their positions, orientations, and perceptions of their environment [35], [36]. This agency must be replicated within virtual worlds to ensure the user's sense of security. Additionally, research has shown that active participation and control over one's environment lead to better retention of events and information [37], [38]. Thus, providing users with the ability to actively shape their virtual surroundings enhances their sense of control.

The concept of control is closely tied to perception, which, in the real world, flows through various modalities such as visual, auditory, and haptic channels. These modalities aid in navigation, information processing, storage, and even survival [39]. In the realm of virtual reality, almost all these modalities can be simulated. However, haptic feedback remains less developed in desktop VR, lagging behind the tactile sensations provided by controllers, gloves, and similar devices. Additionally, replicating olfaction, the sense of smell is currently a limitation in virtual technology. Nevertheless, groundwork has been laid to address these challenges and further enhance sensory immersion in virtual environments [40]–[42].

Special Issue
of the Infocommunication Journal

IV. Research background

A. Subjects

A total of 21 participants were divided into two groups for each condition, and no specific qualifications or expectations were considered when selecting participants. For the 3D VR measurement, 14 participants initially took part, but due to technical issues and breaks in data collection, the results from nine subjects (three women and six men, aged between 17–55 years, with a mean age of 32.5 years) will be published in the analysis. The 2D environment study involved seven participants (four women and three men, aged between 25–33 years, with a mean age of 27.83 years). All participants were Hungarian native speakers, volunteering for the experiment with informed consent obtained in advance. The research was conducted under institutional endorsement ensuring ethical compliance and data privacy.

B. Procedure

This study explores some of the cognitive capabilities of users in desktop VR environments by comparing spatial behaviours, performance, and subjective experiences between traditional 2D interfaces and immersive 3D VR settings. At the initiation of the session, participants engaged in the prescribed task within three dimensions were requested to demonstrate their familiarity with the MaxWhere software and provide an estimation of the time they had allocated to using the application. Those participants who lacked prior knowledge of the software practised for around 30 minutes in acquainting themselves with its functionalities and acquiring fundamental user capabilities. Proficiency in essential skills encompassed adept navigation within the software, as well as the ability to activate and deactivate the display panels and engage with the content presented on them. The evaluators assessed the mastery of proficient software utilization. Participants were tasked with studying materials related to astronomy and completing questionnaires in either a 2D environment hosted on Google Sites or a 3D environment using the MaxWhere desktop VR platform. Despite using identical study materials and questionnaires in both settings, they were presented differently: linearly in the 2D interface and spatially in the 3D VR environment as shown in Figure 1. The questionnaires that were specifically designed to align with each of the subtopics were composed of a series of true-or-false questions, a set of multiple-choice questions, as well as a collection of questions that necessitated brief responses typically consisting of only one or two words. The task was a reading comprehension exercise which is very common in education and also in work scenarios, where participants found all the necessary information in the digital materials placed around the questionnaires. These materials were essential for answering the questions posed in the questionnaires. One example of the true-or-false question type: ”Black holes can be observed through their gravitational effects on the surrounding gas, dust, and stars. True or False?” - The participants were asked to find the information around the questionnaire in on of the related digital contents and mark in the questionnaire the right answer.

The theme of all questionnaires revolved around astronomy. The four subthemes of the questionnaires were (“*Universe*”, “*Planets*”, “*Satellites*” and “*Space Research*”). We chose this topic because none of the participants were experts in the field, ensuring that they approached the tasks with similar levels of knowledge. This prevented any significant disparities in results caused by someone being highly knowledgeable in certain areas and potentially skewing the measurement outcomes.

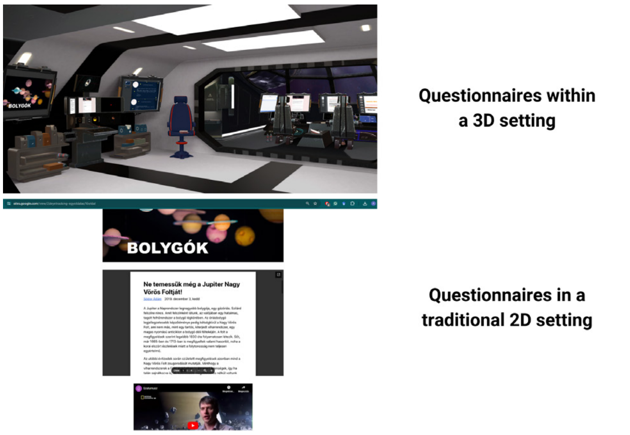

Fig. 1. This Figure illustrates through an example that the same digital content and questionnaires appeared for participants in both the 2D and 3D scenarios. The difference was visibly apparent in the layout mode.

C. Technical background

We used an HP Omen 15 laptop for conducting the research, which had the following specifications:

- AMD Ryzen™ 7 5800H processor
- NVIDIA® GeForce RTX™ 3060 graphics card
- 15.6-inch screen
- 16 GB RAM
- 512 GB SSD

The device used for Eye Tracking measurements was an EyeTribe eye tracker along with OGAMA (Open Gaze and Mouse Analyzer) Version 5.1 software. Since the VR software used for the measurement was a desktop VR application, it did not require the use of extra peripherals (such as an HMD). The eye-tracker was positioned at the bottom of the screen at an appropriate angle, ensuring accurate and consistent data collection for each individual.

D. Experimental environment design

When designing the virtual environment, special attention was paid to incorporating the experiences gained from previous research into the 3D virtual space created for this measurement. Ensuring dynamic interaction with the content was an important consideration because we assumed that such a setup would better meet the demand for a holistic overview of the educational materials, similar to placing documents on a physical desk. This could potentially lead to more effective learning outcomes and more effective performance compared to the more static and linear presentation of materials in the 2D environment.

The experiment was designed with several key objectives structured around both quantitative and qualitative assessments:

Objective Performance Metrics, This includes quantifiable data such as:

- The total number of correct answers participants provided.
- The amount of time participants spent completing the questionnaires.

Subjective Assessment: This assessment was based on the participants' personal evaluations of:

- The difficulty level of the questionnaires.
- Interaction Patterns in a 3D Environment: The study also examined how participants interacted within a three-dimensional (3D) environment, focusing on specific behaviours and engagement methods.

V. Research Results

A Mann-Whitney U test was used to compare the scores of the 3D Group (Mdn = 614.07) and the 2D Group (Mdn = 317.16) (descriptive statistic in Fig. 1) on the fixation duration mean. The Mann-Whitney U statistic was U = 55, indicating a significant difference between the two groups ($p = 0.012$) (Fig. 2).

	Fixation Duration Mean (ms)	
	2D	3D
Valid	7	9
Missing	0	0
Mean	766.390	311.948
Std. Deviation	558.407	42.459
Minimum	289.074	254.968
Maximum	1916.796	392.029

Fig. 2. Descriptive statistics of the fixation duration mean between the two measured groups.

We conducted an independent samples t-test to assess the differences between 2D and 3D environments across various thematic sections. Each analysis was preceded by a Levene Test for Equality of Variances, confirming homogeneity in variances across comparisons. The results indicated no significant differences between the groups, except in the time required to complete the satellite-themed questionnaire. Participants in the 3D environment completed this task noticeably quicker (units of measure were minutes), showing a significant difference ($t(14) = 3.38$, $p < 0.05$).

In the 3D virtual space, participants found the sections on Satellites and the Universe the most challenging, with an average score of 4.25 out of 7 (SD: 1.6). This was followed by the Planets section with a score of 3.75 (SD: 1.42), and

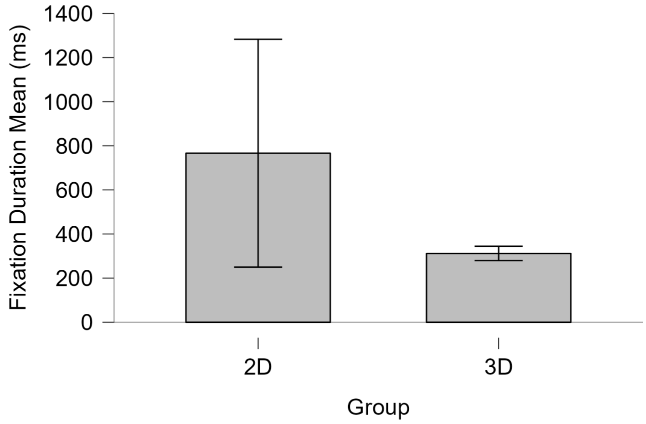

Fig. 3. Fixation duration mean differences between the 3D VR and the 2D group.

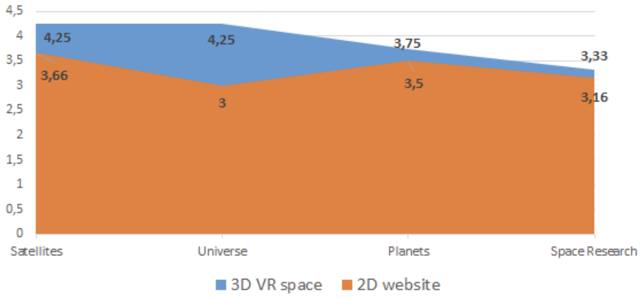

Fig. 4. Subjective user feedbacks - Comparative difficulty and performance in 2D vs. 3D virtual learning environment.

the Space Research section was the easiest at 3.33 points (SD: 2.01). Conversely, participants navigating the 2D website rated the Satellites section as the most difficult, scoring an average of 3.66 (SD: 1.63), followed by Planets at 3.5 (SD: 1.22), Space Research at 3.16 (SD: 1.94), and the Universe section as the easiest with a mean score of 3 (SD: 1.095). Fig 3. shows the research results connecting to these user feedbacks.

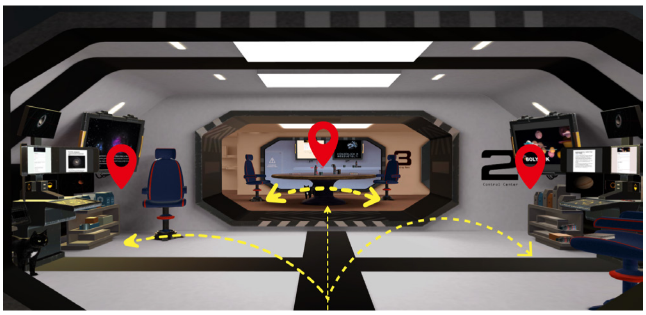

Fig. 5. Interaction routes and overview point examples.

Based on the analysis of screen recordings, a prevalent interaction patterns (Figure 5.) observed among the participants in the 3D measurement was what we refer to as the "overview mode". The red marks in Figure 5. indicate some examples

Recommendation	Description	Relevant research results
Improve Multimodal Stimulus and Feedback	Use auditory and visual contents and feedback to enhancing immersion and information delivery.	- Subjective assessment of the difficulty level of the questionnaires - 2D 3D differences and content analysis
Ensure Consistency	Apply consistent UI/UX design principles, accommodating dynamic VR interactions and perspectives.	- Information overview - Fixation duration time results
Minimize Textual Instructions	Prioritize visual and spatial cues over textual content for guidance, supporting seamless user engagement.	- Subjective assessment of the difficulty level of the questionnaires - Fixation duration time
Incorporate Familiar Elements	Utilize familiar interfaces and interaction models from 2D environments to improve VR usability and ease the transition.	- Overview interaction - Fixation duration time.
Strategic Content Placement	Organize digital content for easy navigation and task management, using circular arrangements and prominent viewpoints.	- Overview, alternating view.
Optimize Object and Content Placement	Consider the size, type, and spatial relationships of content and objects to support tasks without excessive cognitive load.	- Fixation duration time - Overview and alternating view

Fig. 6. Design recommendations for workflow-oriented desktop VR spaces.

of the overview points and the yellow paths represent the interaction pathways throughout the space, that we identified based on the video analyses. In this mode, users sought a position for each block where all materials related to the block were well-visible and comprehensible. Additionally, an alternating pattern was also evident, similar to displaying parallel windows in 2D. In this case, users held two or more windows in a single view and toggled between active windows with clicks to perform tasks, thus saving time, navigation efforts, and energy.

VI. Discussion

The longer one needs to focus on a particular area, the greater the mental effort required for the user to complete the task or other common activity. In the presented measurement, the mean fixation duration of individuals participating in 2D and 3D measurements was observed. Upon analysis, we found that the mean fixation duration of individuals solving tasks in the 3D VR space was significantly lower than the control group working on the traditional 2D homepage. At the end of each questionnaire, participants were asked to rate the difficulty of the task block on a Likert scale, and at the end of the measurement, a closing questionnaire was administered asking which questionnaire they found most challenging. The questionnaires revealed that although individuals solving VR tasks rated each block slightly more difficult than the control group solving tasks in 2D, there was no significant difference in correctness of the answers and in completion time between the two groups. Furthermore, the mean fixation duration did not support this subjective evaluation; in fact, it indicated the opposite. At the beginning of the measurement, all users were familiar with the use and basic functioning of the 3D software. However, it became clear during the survey and evaluation of the results that due to the layout and design of the space, there was a need for precise navigation between individual blocks in the virtual space, and they were not able to find only a few preference points to see through the whole space, which could negatively affect the user experience. Additionally, observing the users' movements in the space, it is evident that the size and placement of the displays holding digital content in the 3D space also require reconsideration in the future. Although the questionnaires were always centrally located with the necessary content around them, the size and placement varied within the blocks. It would be advisable in the future to restructure these elements so that users are assisted by similar layouts during task completion. For example, videos, PDFs, etc., could be located in the same position in each block and of similar size.

Furthermore, a recurring pattern was that users treated the images containing the titles of blocks as content rather than labels. Therefore, another suggestion for future design is to fully separate the titles/content elements of the content blocks to prevent users from attempting interaction with them and to serve solely as information. Interpreting the results and analyzing user behavior suggests that further optimization and modification of the designed 3D virtual space are necessary to maximize the user experience. To achieve this, we propose the following guidelines.

VII. Designing the Future: Guidelines for VR Development

In virtual environments, user experience hinges on control and presence, crucial elements highlighted by research [32]–[34]. Users' ability to exercise agency in virtual spaces mirrors their actions in the real world, fostering engagement and a sense of security [35], [36]. Active participation and control not only enhance user engagement but also significantly contribute to improved information retention [37], [38]. While tactile feedback in virtual reality may not fully replicate real-world sensations, strategic implementations such as haptic feedback through controllers or gloves aim to enrich the immersive experience [43]. Similarly, auditory cues complement visual elements, aiding users in understanding actions and enhancing their sense of presence [44], [45].

Consistency in design is paramount across various viewing angles and orientations in virtual environments to ensure a seamless user interaction [46], [47].

In previous research within the field of CogInfoCom an cVR, studies [24], [48] have identified key preference points in desktop VR workspaces. In addition, the current study's finding of a significantly shorter fixation duration time in 3D VR underlines the importance of spatial instructions and visual signals in navigating virtual environments. This suggests immersive experiences are more effective than extensive textual guidance [49], [50] in enhancing user commitment. Furthermore, incorporating familiar design elements into these spaces not only increases user comfort but also facilitates task completion [51], [52] [50], [51].

Based on the results of this study on interaction patterns and previous research results of the author regarding the workflow oriented VR spaces, we conclude that effective grouping and clustering of content are essential in virtual workspaces to enhance user experience and effectiveness [24], [48]. Circular arrangements of content groups support holistic overview modes, aiding task monitoring and navigation [24], [53]. Considering the size of virtual spaces is vital to prevent cognitive overload and time loss, with predefined spatial elements facilitating user preferences and customization [53].

Content types, including PDFs, images, presentations, videos, and web content, serve varying roles in virtual environments. Users tend to display PDFs on monitors and videos on projector screens, with display orientation impacting user preference, favoring vertical or slightly inclined displays [53]. Introducing flexible display panels allows users to customize layout, number, size, and relationships of placed content, further enhancing user interaction and customization [53].

Summarizing the main findings above, Figure 6. shows the design recommendations of workflow-oriented VR spaces based on the research results of the current study.

By adhering to these recommendations, VR designers can create spaces that are not only immersive and engaging but also intuitive and efficient for users, leveraging the unique capabilities of VR while addressing its current limitations.

VIII. Conclusion

In conclusion, this study highlights the importance of finding the right balance between providing relevant information and managing potential distractions in 3D VR environments. While the inclusion of detailed 3D animations and well-organized content blocks can enhance immersion, it also introduces complexities that may hinder user experience. Despite users' feelings of increased difficulty, objective eye-tracking data suggest that users navigate 3D VR environments effectively, even in the presence of distractions.

Moving forward, further research is needed to refine strategies for optimizing information presentation in 3D VR environments, with a focus on improving user experience and task performance. Simplifying design principles and prioritizing intuitive navigation can help maximize efficiency and user satisfaction in future 3D VR environments. This study underscores the importance of ongoing research and iterative design processes to fully realize the potential of 3D VR technology in the field of the design of digital workflow-oriented desktop VR spaces.

Acknowledgments

The research presented in this paper was supported by the Hungarian Research Network (HUN-REN), and was carried out within the HUN-REN Cognitive Mapping of Decision Support Systems research group.

References

[1] A. Afrooz, L. Ding, and C. Pettit, "An immersive 3d virtual environment to support collaborative learning and teaching," *Computational Urban Planning and Management for Smart Cities 16*, pp. 267–282, 2019. DOI: 10.1007/978-3-030-19424-6_15

[2] N. Pellas, S. Mystakidis, and A. Christopoulos, "A systematic literature review on the user experience design for game-based interventions via 3d virtual worlds in k-12 education," *Multimodal Technologies and Interaction*, vol. 5, no. 6, p. 28, 2021. DOI: 10.3390/mti5060028

[3] J. M. Evangelista Belo, A. M. Feit, T. Feuchtner, and K. Grønbæk, "Xrgonomics: facilitating the creation of ergonomic 3d interfaces," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021, pp. 1–11. DOI: 10.1145/3411764.3445349

[4] Á. B. Csapó, I. Horvath, P. Galambos, and P. Baranyi,"Vr as a medium of communication: from memory palaces to comprehensive memory management," in *2018 9th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*. IEEE, 2018, pp. 000 389–000 394. DOI: 10.1109/CogInfoCom.2018.8639896

[5] B. Berki, "2d advertising in 3d virtual spaces," *Acta Polytechnica Hungarica*, vol. 15, no. 3, pp. 175–190, 2018. DOI: 10.12700/APH.15.3.2018.3.10

[6] S. Negi and R. Mitra, "Fixation duration and the learning process: An eye tracking study with subtitled videos," *Journal of Eye Movement Research*, vol. 13, no. 6, 2020. DOI: 10.16910/jemr.13.6.1

[7] A. Poole and L. J. Ball, "Eye tracking in hci and usability research," in *Encyclopedia of human computer interaction*. IGI global, 2006, pp. 211–219. DOI: 10.4018/978-1-59140-562-7.ch034

[8] R. N. Meghanathan, C. van Leeuwen, and A. R. Nikolaev, "Fixation duration surpasses pupil size as a measure of memory load in free viewing," *Frontiers in human neuroscience*, vol. 8, p. 1063, 2015. DOI: 10.3389/fnhum.2014.01063

[9] B. Albert and T. Tullis, *Measuring the User Experience: Collecting, Analyzing, and Presenting UX Metrics*. Morgan Kaufmann, 2022. ISBN 0124157920, 9780124157927

[10] S. H. Cha, C. Koo, T. W. Kim, and T. Hong, "Spatial perception of ceiling height and type variation in immersive virtual environments," *Building and Environment*, vol. 163, p. 106285, 2019. DOI: 10.1016/j.buildenv.2019.106285

[11] I. Horváth and B. Berki, "Investigating the operational complexity of digital workflows based on human cognitive aspects," *Electronics*, vol. 12, no. 3, 2023. [Online]. Available: https://www.mdpi.com/2079-9292/12/3/528 DOI: 10.3390/electronics12030528

[12] P. Baranyi and Á. Csapó, "Definition and synergies of cognitive infocommunications," *Acta Polytechnica Hungarica*, vol. 9, no. 1, pp. 67–83, 2012.

[13] P. Baranyi, A. Csapo, and G. Sallai, *Cognitive infocommunications (coginfocom)*. Springer, 2015. DOI: 10.1007/978-3-319-19608-4

[14] I. Horvath, Á. B. Csapó, B. Berki, A. Sudar, and P. Baranyi, "Definition, background and research perspectives behind 'cognitive aspects of virtual reality'(cvr)," *Infocommunications Journal: A Publication of the Scientific Association For Infocommunications (HTE)*, no. SP, pp. 9–14, 2023. DOI: 10.36244/ICJ.2023.SI-IODCR.2

[15] I. Horváth and A. Sudár, "Factors contributing to the enhanced performance of the maxwhere 3d vr platform in the distribution of digital information," *Acta Polytechnica Hungarica*, vol. 15, no. 3, pp. 149–173, 2018. DOI: 10.12700/APH.15.3.2018.3.9

[16] P. Baranyi, P. Galambos, Á. Csapó, and L. Jaloveczki, "Cognitive navigation and manipulation (coginav) method," Feb. 1 2018, uS Patent App. 15/658, 579.

[17] I. K. Boda, E. Tóth, M. Bényei, and I. Csont, "A three-dimensional virtual library model of the ancient library of alexandria," 2015. [Online]. Available: https://api.semanticscholar.org/CorpusID:56215123 DOI: 10.14794/ICAI.9.2014.1.103

[18] I. K. Boda, E. Tóth, I. Csont, and L. T. Nagy, "Toward a knowledge base of literary content focusing on the ancient library of alexandria in the three dimensional space," *2015 6th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, pp. 251–258, 2015. [Online]. Available: https://api.semanticscholar.org/CorpusID:25320574 DOI: 10.1109/CogInfoCom.2015.7390600

[19] K. Chmielewska and A. Gilányi, "Mathability and computer aided mathematical education," in *2015 6th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, 2015, pp. 473–477. DOI: 10.1109/CogInfoCom.2015.7390639

[20] K. Chmielewska, A. Gilányi, and A. Łukasiewicz, "Mathability and mathematical cognition," in *2016 7th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, 2016, pp. 000245–000 250. DOI: 10.1109/CogInfoCom.2016.7804556

[21] J. B. Kóczy and L. I. Komlosi, "Revisiting literacy: Changing learning paradigms in digital culture," 2019. [Online]. Available: https://api.semanticscholar.org/CorpusID:204873640

[22] C. S. Lányi and Á. Tilinger, "Multimedia and virtual reality in the rehabilitation of autistic children," in *Computers Helping People with Special Needs*, K. Miesenberger, J. Klaus, W. L. Zagler, and D. Burger, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2004, pp. 22–28. DOI: 10.1007/978-3-540-27817-7_4

[23] J. Li, L. Khoo, and S. Tor, "Desktop virtual reality for maintenance training: an object oriented prototype system (v-realism)," *Computers in Industry*, vol. 52, no. 2, pp. 109–125, 2003. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166361503001039 DOI: 10.1016/S0166-3615(03)00103-9

[24] A. Sudar and A. Csapa, "Interaction patterns of spatial navigation and smartboard use in vr workspaces," in *Accentuated Innovations in Cognitive Info-Communication*. Springer, 2022, pp. 149–166. DOI: 10.1007/978-3-031-10956-0_7

[25] E. D. Ragan, A. Sowndararajan, R. Kopper, and D. A. Bowman, "The effects of higher levels of immersion on procedure memorization performance and implications for educational virtual environments," *PRESENCE: Teleoperators and Virtual Environments*, vol. 19, pp. 527–543, 2010. [Online]. Available: https://api.semanticscholar.org/CorpusID:17361861 DOI: 10.2312/EGVE/JVRC09/121-128

[26] B. Csapó, I. Horváth, P. Galambos, and P. Baranyi, "Vr as a medium of communication: from memory palaces to comprehensive memory management," in *2018 9th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*, 2018, pp. 000 389–000 394. DOI: 10.1109/CogInfoCom.2018.8639896

[27] A. Cannavò and F. Lamberti, "A virtual character posing system based on reconfigurable tangible user interfaces and immersive virtual reality," in *Smart Tools and Applications in Graphics*, 2018. [Online]. Available: https://api.semanticscholar.org/CorpusID:88479188 DOI: 10.2312/STAG.20181297

[28] B. Berki, "Better memory performance for images in maxwhere 3d vr space than in website," in *2018 9th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*. IEEE, 2018, pp. 000 281–000 284. DOI: 10.1109/CogInfoCom.2018.8639956

[29] ——, "Role of presence, memory and spatial ability in a desktop virtual reality," in Accentuated Innovations in *Cognitive Info-Communication*. Springer International Publishing, sep 2022, pp. 79–97. DOI: 10.1007/978-3-031-10956-0_4

[30] ——, "Desktop vr as a virtual workspace: a cognitive aspect," *Acta Polytechnica Hungarica*, vol. 16, no. 2, pp. 219–231, 2019. DOI: 10.12700/aph.16.2.2019.2.13

[31] I. Horváth, "An analysis of personalized learning opportunities in 3d vr," in *Frontiers of Computer Science*, 2021. [Online]. Available: https://api.semanticscholar.org/CorpusID:237587652 DOI: 10.3389/fcomp.2021.673826

[32] S. Weech, S. Kenny, and M. Barnett-Cowan, "Presence and cybersickness in virtual reality are negatively related: a review," *Frontiers in psychology*, vol. 10, p. 158, 2019. DOI: 10.3389/fpsyg.2019.00158

[33] S. Grassini, K. Laumann, and M. Rasmussen Skogstad, "The use of virtual reality alone does not promote training performance (but sense of presence does)," *Frontiers in psychology*, vol. 11, p. 1743, 2020. DOI: 10.3389/fpsyg.2020.01743

[34] N. Cooper, F. Milella, C. Pinto, I. Cant, M. White, and G. Meyer, "The effects of substitute multisensory feedback on task performance and the sense of presence in a virtual reality environment," *PloS one*, vol. 13, no. 2, p. e0191846, 2018. DOI: 10.1371/journal.pone.0191846

[35] A. Tapal, E. Oren, R. Dar, and B. Eitam, "The sense of agency scale: A measure of consciously perceived control over one's mind, body, and the immediate environment," *Frontiers in psychology*, vol. 8, p. 1552, 2017. DOI: 10.3389/fpsyg.2017.01552

[36] M. Velmans, "How could conscious experiences affect brains?" *Journal of Consciousness Studies*, vol. 9, no. 11, pp. 3–29, 2002.

[37] C. Pérez-Sabater, B. Montero-Fleta, M. Pérez-Sabater, B. Rising, and U. De Valencia, "Active learning to improve long-term knowledge retention," in *Proceedings of the xii simposio internacional de comunicación social*, 2011, pp. 75–79.

[38] J. G. Kooloos, E. M. Bergman, M. A. Scheffers, A. N. Schepens-Franke, and M. A. Vorstenbosch, "The effect of passive and active education methods applied in repetition activities on the retention of anatomical knowledge," *Anatomical sciences education*, vol. 13, no. 4, pp. 458–466, 2020. DOI: 10.1002/ase.1924

[39] N. Jayant, J. Johnston, and R. Safranek, "Signal compression based on models of human perception," *Proceedings of the IEEE*, vol. 81, no. 10, pp. 1385–1422, 1993. DOI: 10.1109/5.241504

[40] J. Diemer, G. W. Alpers, H. M. Peperkorn, Y. Shiban, and A. Mühlberger, "The impact of perception and presence on emotional reactions: a review of research in virtual reality," *Frontiers in psychology*, vol. 6, p. 26, 2015. DOI: 10.3389/fpsyg.2015.00026

[41] G. Freeman and D. Maloney, "Body, avatar, and me: The presentation and perception of self in social virtual reality," *Proceedings of the ACM on human-computer interaction*, vol. 4, no. CSCW3, pp. 1–27, 2021. DOI: 10.1145/3432938

[42] F. El Jamiy and R. Marsh, "Survey on depth perception in head mounted displays: distance estimation in virtual reality, augmented reality, and mixed reality," *IET Image Processing*, vol. 13, no. 5, pp. 707–712, 2019. DOI: 10.1049/iet-ipr.2018.5920

[43] H. Benko, C. Holz, M. Sinclair, and E. Ofek, "Normaltouch and texturetouch: High-fidelity 3d haptic shape rendering on handheld virtual reality controllers," in *Proceedings of the 29th annual symposium on user interface software and technology*, 2016, pp. 717–728. DOI: 10.1145/2984511.2984526

[44] M. Hoppe, J. Karolus, F. Dietz, P. W. Woźniak, A. Schmidt, and T.- K. Machulla, "Vrsneaky: Increasing presence in vr through gait-aware auditory feedback," in *Proceedings of the 2019 CHI conference on human factors in computing systems,* 2019, pp. 1–9. DOI: 10.1145/3290605.3300776

[45] A. U. Batmaz and W. Stuerzlinger, "The effect of pitch in auditory error feedback for fitts' tasks in virtual reality training systems," in *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2021, pp. 85–94. DOI: 10.1109/VR50410.2021.00029

[46] S. Bodker, *Through the interface: A human activity approach to user interface design*. CRC Press, 2021. DOI: 10.7146/dpb.v16i224.7586

[47] B. Shneiderman, C. Plaisant, M. Cohen, S. Jacobs, N. Elmqvist, and N. Diakopoulos, *Designing the user interface: strategies for effective human-computer interaction*. Pearson, 2016.

[48] A. Sudár and Á. Csapó, "Interaction patterns of spatial navigation in vr workspaces," in *2019 10th IEEE international conference on cognitive infocommunications (CogInfoCom)*. IEEE, 2019, pp. 615–618. DOI: 10.1109/CogInfoCom47531.2019.9089998

[49] T. Kojić, D. Ali, R. Greinacher, S. Möller, and J.-N. Voigt-Antons, "User experience of reading in virtual reality—finding values for text distance, size and contrast," in *2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX)*. IEEE, 2020, pp. 1–6. DOI: 10.1109/QoMEX48832.2020.9123091

[50] P.-L. P. Rau, J. Zheng, Z. Guo, and J. Li, "Speed reading on virtual reality and augmented reality," *Computers & Education*, vol. 125, pp. 240–245, 2018. DOI: 10.1016/j.compedu.2018.06.016

[51] A. M. Cleary, A. S. Brown, B. D. Sawyer, J. S. Nomi, A. C. Ajoku, and A. J. Ryals, "Familiarity from the configuration of objects in 3-dimensional space and its relation to déjà vu: A virtual reality investigation," *Consciousness and cognition*, vol. 21, no. 2, pp. 969–975, 2012. DOI: 10.1016/j.concog.2011.12.010

[52] A. Almutawa and R. Ueoka, "The influence of spatial awareness on vr: investigating the influence of the familiarity and awareness of content of the real space to the vr," in *Proceedings of the 2019 3rd International Conference on Artificial Intelligence and Virtual Reality*, 2019, pp. 26–30. DOI: 10.1145/3348488.3348502

[53] A. Sudár and Á. B. Csapó, "Elicitation of content layout preferences in virtual 3d spaces based on a free layout creation task," *Electronics*, vol. 12, no. 9, p. 2078, 2023. DOI: 10.3390/electronics12092078

Ildikó Horváth obtained her PhD degree in 2017 and in 2023 completed her habilitation in Information Sciences. Her research focuses on the examination of the cognitive aspects of 3-dimensional alternative reality (VR, AR, Mixed reality) systems. The research goal is to determine the directions of development in digital ICT environments that ensure users' work with the most optimal cognitive load, thus positively impacting work efficiency. It also investigates the effects of digital environments on changes in human abilities and the possibilities of personalization. Shas experience in leadership, organization of education and development, and over 10 years of experience in scientific research, publishing, and university education for BSc, MSc, and PhD levels.

Anna Sudár obtained her PhD degree in 2023 in the field of computer science and holds an MSc degree in cognitive science. Her research topic is spatial cognition and the examination of general cognitive abilities in virtual reality. She has more than fifteen scientific publications including a book chapter. In the past 6 years as a scientific community activity, she participated in the organization of several international IEEE conferences and helped the editorial processes of many international Special Journal Issues.