a b

Figure 1: Early prototype of an VR information retrieval interface with virtual keyboard for query input (a) and 3D thumbnails for result representation (b).

Towards the ultimate search interface - A research plan

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Abstract

In interactive information retrieval (IIR), the interaction between humans and primarily digital information is studied. Meanwhile, computerised virtual reality (VR) continues to evolve on a technical and abstract level. While there has been some research on information retrieval (IR) systems for VR, no research fully encompasses the approach of including human information seeking (IS) behaviour when considering search in VR. This research plan suggests just that. For this, recent existing research is briefly overviewed, and several exploratory studies are proposed. While some existing software artefacts exist, this plan suggests the development of prototypes that allow the analysis of the effects of IR features and the search interface on information seeking in VR. The many choices and challenges regarding the design of these studies are also presented for discussion.

Keywords

Virtual Reality, Interactive Information Retrieval, Information Seeking, Information Search Behaviour, Human-Computer Interaction,

1. Introduction

Ivan Sutherland's *Sword of Damocles*, is widely regarded as the first digital virtual reality (VR) system [1]. Even earlier, in 1965, he envisioned the *ultimate display*, "[...] a room in which the computer can control the existence of matter" and that "[a] chair displayed in such a room would be good enough to sit in" [2]. Today's VR systems are still far away from providing such an experience [3]. It is difficult even to imagine what user interfaces for Sutherland's ultimate display would look like. However, with recent technical advances in VR technology, many existing and new theories can be explored and studied more easily. An interesting question arises regarding the human effort to seek and retrieve more complex information within digital systems: **What is the ultimate interface for human information seeking?**

Utilising 3D interfaces for information seeking (IS) and information retrieval (IR) is not a new idea. Wilson summarised in 2013 on 3D search interfaces: "While many of these ideas are exciting, they have rarely been shown to provide significant improvements to searchers" [4]. Wilson continues: "Essentially, the overhead of manipulating and navigating through a 3D space currently overrides the benefits of adding the third dimension." However, this refers to 3D interfaces that are projected onto 2D displays (e.g. a laptop or desktop computer). Humans are used to perceiving and interacting with 3D space in the real world. Arguably, they should benefit from 3D search interfaces if they are presented in an immersive 3D virtual environment, such as with VR headsets and hand-tracked input. There is already evidence that VR can be beneficial for data visualisation [5, 6] and that users overall better in visual search tasks in VR [7, 8]. With such benefits in mind, is it possible to design a search interface in VR that significantly improves information search?

Research in VR dates back to the early days of digital computing [9]. However, enabled by technological advances in display technology and real-time rendering of 3D computer graphics, the release of the Oculus Rift VR headset marks a renewed interest in VR, including research. An analysis of publications in the Web of Science core collection that mention *Virtual Reality* in the title, keywords or abstracts shows that more than 30 % of all records between 1987 and 2021 have been published in the last three years (almost 55 % since 2016).

As overviewed in the following section, the intricacies of human information seeking behaviour in virtual reality remain largely unexplored. Consequently, the implications of this seeking behaviour for information retrieval systems are also unknown. Therefore, the overarching goal of this research plan is to understand information seeking activities in virtual reality, focusing on the involved cognitive behavioural processes and their consequences on the design of VR information retrieval systems. To that extent, the following preliminary research questions are formulated:

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RQ1: **How can information needs between users and a VR information retrieval system be communicated effectively?**
RQ2: **How can search result representation in VR systems look like, and what factors influence their effectiveness?**
RQ3: **What is good general UI interaction for VR search systems?**
RQ4: **Can existing information seeking process models be applied to information seeking in virtual reality?**

2. Background

For this research plan, virtual reality (VR) means immersive virtual reality experiences, typically produced with VR headsets (and with computers and other hardware). It can be included in the term extended reality (XR) which also encompasses augmented reality (AR) and mixed reality (MR), where the actual reality is included visually to some degree. Arguably, this can be expected to add additional complexity to a 3D search interface, and thus, AR and MR are currently not included in this research plan.

Several research disciplines and applied fields are involved in understanding human information search and implementing search software systems. From a academic perspective and embedded in Computer Science, the term *information retrieval* describes "[…] finding material […] of an unstructured nature […] that satisfies an information need from within large collections […]" [10]. Quite similarly, but coming from Information and Library Science, *information seeking* describes the "[…] conscious effort to acquire information in response to a need or gap in your knowledge" [11]. A concrete terms is *interactive information retrieval*, where attention is payed to the human and their interaction with the system [12] and *information search behaviour*, limiting the seeking activity to active search within computer-based systems [13]). Among others, Ingwersen & Järvelin [14], Saracevic [15] and Cool & Belkin [12] give an account of the history of the fields and how it is beneficial to include perspectives from both fields when studying human information search. Figure 2 shows a suggested relation between human information seeking, information retrieval features and search user interface design for virtual reality scenarios. Related disciplines include information science, computer science, psychology and the overarching human-computer interaction, involving the fields information seeking, information retrieval, virtual reality and cognitive psychology. This results in a complex and interdisciplinary research interest.

2.1. Existing research

Regarding existing studies about information retrieval in virtual reality, a recent literature review overviews 16 current systems and theoretical considerations [16]). These include novel query and interaction methods, including rapid typing with hand-tracked input [17], utilising voice-commands [18] or user-created 3D sketches [19]. In result representation, "[r]esults were visualised as curved text, flat, spherical, curved or cylindrical image grids, planets or floating 3D objects" [16]. Evaluations of such systems often showed good user task performance and equal or faster task times compared to conventional 2D systems. In all studies that reported user satisfaction, the VR version was prefered [16]. Although the novelty of VR experiences

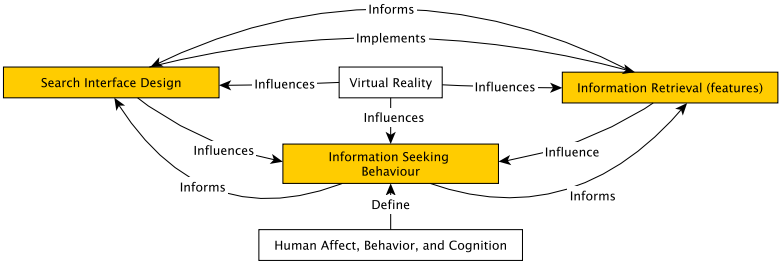

Figure 2: Suggested relation between information seeking, information retrieval and search interface design in virtual reality.

can affect reported user satisfaction. These existing works often focus on one specific IR or user design feature without considering the larger context of interactive information retrieval or information seeking. Most pressingly, no existing research pays special attention to the human factors that influence the design of IR features and systems at large. Such factors could be human affection, cognition and behaviour in general, as it is sometimes included in information seeking models, but also from the effects of humans being immersed in a virtual reality experience specifically.

Recent works that consider the human role in relation to search interfaces for VR include encouraging words by White [20] as well as Liu et al. [21], where both suggest that search in VR or XR deserves further investigation. Some of the few recent studies that go beyond technical implementations are conducted by Ward [22, 23], who considers result representation, interaction and the design of abstract information objects.

Several information seeking models and theories explain human information-seeking behaviour with digital IR systems (overviews given by[21, 24, 14]). Liu et al. [21] categorise models that describe only some of the information seeking activities (Belkin's ASK hypothesis [25], Bates' berry-picking model [26] and Pirolli's information foraging [27]); those that describe information seeking as a process (Kuhlthau [28], Ellis [29] and Marchionini [30]); models that focus on the representation of search interactions (Belkin's episode model [31]) or information objects (Ingwersen's cognitive model and polyrepresentation [14]); and finally Saracevic's stratified model as an integrative model ([32]). Notably, no scientific works directly connect information seeking models or theories with virtual reality. Currently, it is unclear which information seeking models can be applied to search in VR and to which extent. Thus, such models and theories should be (re-)investigated for digital search in virtual reality. Given the generalisability of some of the models and the involvement of a human user, hypothetically, information seeking in VR is still strongly connected to humans and their cognitive processes, as suggested by Bates, Belkin, Pirolli and Ingwersen. Further information seeking in VR could possibly still be described as a process, as modelled by Kuhlthau, Ellis, Marchionini and Belkin. Finding more definite evidence is an important part of this research plan (see RQ4).

From a completely different perspective, experiences in virtual reality could be, or already are, much closer to the way humans interact with actual reality when compared to 2D user interfaces on computers or smartphones.*Natural user interfaces*, have interactions that are closer to human interaction with actual objects [33]. 3D spatial input is preferred in current commercial VR

systems, either with 3D tracked controllers or direct hand tracking. Interactive information retrieval in VR could be inspired by human interaction with information in actual reality. Kilian describes a research plan for closer examination of human information behaviour at an airport [34]. Similar investigations into scenarios where information behaviour, especially information seeking, is of high relevance (e.g. libraries or hospitals) could inform the design of information retrieval systems in VR.

3. Proposed Research Design

3.1. General considerations

Several decisions need to be made and will impact the direction future research can take. For some of these decisions, solutions are suggested based on existing work and logical argumentation. Most importantly, the FDIA consortium will be a platform to discuss these points and can hopefully improve the suggested research plan. These decisions will also be reevaluated based on observations and findings of the first qualitative research phase.

What systems can be evaluated? Currently, no public software systems focus on information retrieval in virtual reality. When search functionality is needed (e.g. to search for applications in a software store), it is often implemented similarly to existing 2D interfaces (e.g. the SteamVR store, the Oculus Quest store and others). To really study human information seeking behaviour and interactive information retrieval, one needs to create software artefacts that do not just replicate 2D search interfaces. If such systems emerge in the coming years and reach maturity and widespread use, they should also be studied. For now, this results in formative evaluation during the system's development, as opposed to summative evaluation of a mature system [35]. Software artefacts need to be both developed and evaluated.

What software artefacts can be evaluated? In a fully developed search software monolith that implements various IR features and many information seeking steps, extensive evaluation of both the system and the human would be possible. Since no such systems exist (especially not recent and widely used ones), this is not possible. Thus, it is suggested to start with developing and evaluating individual IR components that encompass individual steps of the IS process. In addition, later work can adapt the individual components into a fully-fledged system and affirm previous discoveries.

What are adequate means of comparison? At some point, to get quantitative data, comparative evaluation is needed. Currently, it is challenging to find an adequate baseline to compare to. There are only few candidates of existing VR software with information retrieval functionalities that even have conventional (2D desktop) equivalents. These could be studied in either an early exploratory approach or much later to confirm the insights from previous studies of single IR components. This is especially attractive because comparative, quantitative methods can be applied. On the other hand, such studies already exist and often conclude that information retrieval in VR results in worse task performance which in turn is then often explained with

the novelty of such systems and that users are more used to 2D systems (and therefore are e.g. faster or less error-prone) [36, 37, 38, 39, 40, 41, 18]. If 2D and VR systems should be compared, it should either be with subjects that are well-versed in the use of VR systems or with means of comparison that are not affected by the novelty of VR.

How can study participants be selected? For studies in general, participants' demographic attributes are relevant (e.g. age, sex, education, etc.). For studies in this research plan, it is additionally of interest to assess the level of exposure to (recent) VR technology and experiences. This can include first-time users, average users and enthusiasts. Possibly, different groups would approach information seeking in VR very differently. A starting point is to avoid first-time VR users as participants, as the novelty of experiencing VR tends to overshadow whatever should be measured. On the other hand, VR enthusiasts or even researchers might bring several preconceptions and opinions with them that affect their judgement.

Which databases should be searched? There is a wide range of different datasets that include texts, images, sounds, videos and 3D objects, as well as descriptive metadata. Choices need to be made regarding what data is used and how it is displayed. It is suggested to prioritise datasets that primarily contain non-textual data since such data can be displayed easily within today's VR headsets and in 3D space. An open discussion point is that study participants are potentially less familiar with the retrieval of 3D data. On the other hand, multimedia data is a reality of current general search engines such as Google, where images, videos and other information objects are included in the search results.

Other considerations There are other things to consider, such as the general approach to the interaction between the user and interface elements, objects in the virtual world and even other users (collaborative information seeking/retrieval). Further, should the user always embody an avatar (a virtual self-representation) in VR? What *superpowers* (teleportation, telekinesis, flying, …) do they need to maximise the usefulness of an IR session in VR? How do physical, physiological and psychological limitations need to be considered for information retrieval VR sessions specifically (e.g. spacial restrictions, comfort, cognitive load, …)?

3.2. An exploratory approach

No complete and comprehensive research effort exists that investigates interactive information retrieval in VR. Thus, new exploratory research needs to be done. Reference works on research methodology and design often suggest an exploratory-sequential approach, where qualitative observations inform the design of the following quantitative approaches [42, 43]. Similarly, in the first phase of this approach, qualitative findings can inform the design of the component of a VR search system, identify relevant variables and provide the first indications of human search behaviour within such a system. In the second phase, quantitative data can support or reject more concrete hypotheses that will be formulated based on the research questions of this research plan, as suggested by Kelly citekellyMethodsEvaluatingInteractive2009. Overall, Kelly gives a detailed overview of general research approaches and experimental design and data collection methods and will serve as a basis for the design of the studies of this research plan.

3.3. Potential studies

Some future studies can be conceptualised to work towards answering the introduced research questions. It is unlikely that these questions can be answered entirely with this research plan. They should be considered prelimineray and will be further discussed at the FDIA event.

It is suggested that one of the information seeking process models serves, at least initially, as the guiding structure for this research plan. As illustrated in Figure 2, human information seeking, information retrieval features and the search user interface design are interrelated and must be considered throughout the research plan. Early qualitative work could include a detailed examination of information-seeking behaviour in VR at the single case level to build hypotheses. In later quantitative work, these hypotheses can be validated, and variations in IR features and interface design can be compared directly.

Preliminary studies In early preliminary studies, detailed observation and interviews can inform the design of all further research efforts. Here, the aim is to solidify the research questions and overall research plan and unearth any logical flaws. As previously mentioned, there are a few candidates of existing software in VR with information retrieval functionalities and conventional (2D desktop) equivalents. These could be studied exploratory or with comparative, quantitative methods. Alternatively, a small study with a simplistic IR prototype in VR could be conducted. Some possible features of such a system are shown in Figure 1.

Study 1: (Re)designing the query for VR search To work towards answering RQ1 (How can information needs between users and a VR information retrieval system be communicated effectively?), this exploratory study focuses on the design of the search query. Existing paradigms in traditional interfaces need to be examined, including mouse and keyboard interaction with a desktop computer or laptop, but also more recent developments such as search interfaces on smartphones and voice-based search ([18]) and personal assistants (e.g. Alex, Siri, Google Assistant) and even existing VR interfaces that utilise tracked controllers or hands (e.g. [17]). Not only the input technology is of interest, but also the query construction itself (e.g. [19]). Results of this study also give indications to answer RQ3 (What is good general UI interaction for VR search systems?).

Study 2: Result representation and browsing Regarding RQ2 (How can search result representation in VR systems look like, and what factors influence their effectiveness?), this exploratory study focuses on the result representation (SERPs) and how these results are interacted with. Existing paradigms in traditional interfaces could be examined, including mouse and keyboard interaction with a desktop computer or laptop. But, also more recent developments such as smartphone search interfaces and voice-based search via personal assistants (Siri, Hey Google, Alexa). There is a body of existing work that can inform the design of an optimised prototype for further evaluation (see [16]). Results of this study should give further indications to answer RQ3 (What is good general UI interaction for VR search systems?).

Study 3: Information Extraction This study is directly related to both RQ 1 (good queries in VR) and RQ2 (good SERPs in VR). The study could focus on how information can be extracted

by users in a VR context. As Kelly noted, "[a] user's information need is perhaps one of the most critical aspects of information seeking and retrieval". Evaluations could feature generated information needs and corresponding tasks. Since there is evidence that the spacial aspect of VR can aid memory retention [44], are there similar effects for information search?

Study 4: Interactive Information Retrieval in Virtual Reality This study finishes the research effort and should answer RQ3 (What is good general UI interaction for VR search systems?) and RQ4 (Can existing information seeking process models be applied to information seeking in virtual reality?). In a final descriptive or even explanatory study and based on the results of the previous studies, an information retrieval system that encompasses the entire information seeking process should be conceptualised, prototyped and evaluated. Thus, this system should enable users to formulate and execute a query in a way that is adequate for the requirements of VR environments. The results of such a query need to be presented in a way that is native to a 3D environment yet optimised for human consumption. Finally, a user needs to be able to extract all relevant information directly from the VR system. Results of this study could lead to the development of the first theories of interactive information retrieval in virtual reality and even be a building block for the conceptualisation of a theory of general information seeking in virtual reality.

4. Final Remarks

This research plan does not formulate an interest in the evaluation of the performances of specific IR systems (especially concerning retrieval algorithms). Instead, established pre-build IR software systems will be picked to focus on IR features, the search user interface and their effect on the information seeking process, or interactive information retrieval in VR.

As [45] puts it so succinctly: "Complexity reigns in information seeking-behaviour research." This is all the more true for such research within VR systems, where is almost no existing research. This research plan formulates ambitious goals and aims to cover much ground. Possibly, even first investigations will uncover new challenges and raise new questions. However, this is part of the process of explorative research in novel areas, which information search in VR certainly is. The author hopes that both the ESSIR conference and the FDIA consortium can act as a funnel and amplifier for the formulated research interested in improving the research plan and inspiring other researchers to set their gaze on this promising research area. Suppose VR (or XR) technologies become widely used in productive contexts. In that case, the design of IR systems that fully leverage the advantages of 3D space and direct user input will become a major task for the IR community.

In 2013, in a foreword in Ruthven & Kelly's book on *Interactive Information Seeking, Behaviour and Retrieval*, Saracevic listed contemporary leading research questions regarding information search (on the internet): "What is the nature of the search? [...] What are its manifestations and effects? How is it affected? [...] What helps or hinders a search?" [15]. The research plan suggested in this paper lays out the first steps to answer these questions, albeit be it *only* for human information search in virtual reality.

References

[1] I. E. Sutherland, A head-mounted three dimensional display, in: Proceedings of the December 9-11, 1968, Fall Joint Computer Conference, Part I, AFIPS '68 (Fall, Part I), Association for Computing Machinery, New York, NY, USA, 1968, pp. 757–764. doi:10.1145/1476589.1476686.

[2] I. Sutherland, The Ultimate Display, in: Proceedings of the IFIPS Congress 65(2):506-508. New York: IFIP, CUMINCAD, 1965.

[3] V. Angelov, E. Petkov, G. Shipkovenski, T. Kalushkov, Modern Virtual Reality Headsets, in: 2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), 2020, pp. 1–5. doi:10.1109/HORA49412.2020.9152604.

[4] M. Wilson, Interfaces for information retrieval, in: I. Ruthven, D. Kelly (Eds.), Interactive Information Seeking, Behaviour and Retrieval, first ed., Facet, 2013, pp. 139–170. doi:10.29085/9781856049740.010.

[5] P. Millais, S. L. Jones, R. Kelly, Exploring Data in Virtual Reality: Comparisons with 2D Data Visualizations, in: Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems, ACM, Montreal QC Canada, 2018, pp. 1–6. doi:10.1145/3170427.3188537.

[6] B. Lee, D. Brown, B. Lee, C. Hurter, S. Drucker, T. Dwyer, Data Visceralization: Enabling Deeper Understanding of Data Using Virtual Reality, IEEE Transactions on Visualization and Computer Graphics 27 (2021) 1095–1105. doi:10.1109/TVCG.2020.3030435.

[7] R. Pausch, D. Proffitt, G. Williams, Quantifying immersion in virtual reality, in: Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH '97, ACM Press, Not Known, 1997, pp. 13–18. doi:10.1145/258734.258744.

[8] J. C. M. Figueroa, R. A. B. Arellano, J. M. E. Calinisan, A Comparative Study of Virtual Reality and 2D Display Methods in Visual Search in Real Scenes, in: D. N. Cassenti (Ed.), Advances in Human Factors in Simulation and Modeling, volume 591, Springer International Publishing, Cham, 2018, pp. 366–377. doi:10.1007/978-3-319-60591-3_33.

[9] J. Jerald, A History of VR, in: The VR Book, Association for Computing Machinery, 2015. doi:10.1145/2792790.

[10] C. D. Manning, P. Raghavan, H. Schütze, Introduction to Information Retrieval Introduction, volume 35, 2008. doi:10.1162/coli.2009.35.2.307.

[11] D. O. Case, L. M. Given, Information Behavior: An Introduction, in: Looking for Information: A Survey of Research on Information Seeking, Needs, and Behavior, Studies in Information, fourth edition ed., Emerald, Bingley, UK, 2016.

[12] C. Cool, N. J. Belkin, Interactive information retrieval: History and background, in: I. Ruthven, D. Kelly (Eds.), Interactive Information Seeking, Behaviour and Retrieval, first ed., Facet, 2013, pp. 1–14. doi:10.29085/9781856049740.003.

[13] T. Wilson, Models in information behaviour research, Journal of Documentation 55 (1999) 249–270. doi:10.1108/EUM0000000007145.

[14] P. Ingwersen, K. Järvelin, The Turn: Integration of Information Seeking and Retrieval in Context, Kluwer International Series on Information Retrieval, Springer, Dordrecht, 2005.

[15] T. Saracevic, Foreword, in: I. Ruthven, D. Kelly (Eds.), Interactive Information Seeking,

Behaviour and Retrieval, first ed., Facet, 2013. doi:10.29085/9781856049740.
[16] M. Schleußinger, Information retrieval interfaces in virtual reality—A scoping review focused on current generation technology, PLOS ONE 16 (2021) e0246398. doi:10.1371/journal.pone.0246398.
[17] J. Fashimpaur, K. Kin, M. Longest, PinchType: Text Entry for Virtual and Augmented Reality Using Comfortable Thumb to Fingertip Pinches, in: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, CHI EA '20, Association for Computing Machinery, New York, NY, USA, 2020, pp. 1–7. doi:10.1145/3334480.3382888.
[18] D. Henriques, LSpeakIt : Immersive interface for 3D object Search, 2014.
[19] D. Giunchi, S. James, A. Steed, 3D sketching for interactive model retrieval in virtual reality, in: Proceedings of the Joint Symposium on Computational Aesthetics and Sketch-Based Interfaces and Modeling and Non-Photorealistic Animation and Rendering, ACM, Victoria British Columbia Canada, 2018, pp. 1–12. doi:10.1145/3229147.3229166.
[20] R. W. White, Interactions with Search Systems, Cambridge University Press, Cambridge, 2016. doi:10.1017/CBO9781139525305.
[21] C. Liu, Y.-H. Liu, J. Liu, R. Bierig, Search Interface Design and Evaluation, NOW PUBLISHERS, S.l., 2021.
[22] A. R. Ward, R. Capra, Immersive Search: Using Virtual Reality to Examine How a Third Dimension Impacts the Searching Process, in: Proceedings of the 43rd International ACM SIGIR Conference on Research and Development in Information Retrieval, ACM, Virtual Event China, 2020, pp. 1621–1624. doi:10.1145/3397271.3401303.
[23] A. R. Ward, Y. Gu, S. Avula, P. Chakravarthula, Interacting with Information in Immersive Virtual Environments, in: Proceedings of the 44th International ACM SIGIR Conference on Research and Development in Information Retrieval, ACM, Virtual Event Canada, 2021, pp. 2600–2604. doi:10.1145/3404835.3462787.
[24] I. Ruthven, D. Kelly (Eds.), Interactive Information Seeking, Behaviour and Retrieval, first ed., Facet, 2013. doi:10.29085/9781856049740.
[25] N. J. Belkin, A Concept of Information for Information Science., Ph.D. thesis, University College London (University of London), 1977.
[26] M. J. Bates, The design of browsing and berrypicking techniques for the online search interface, Online Review 13 (1989) 407–424. doi:10.1108/eb024320.
[27] P. Pirolli, S. Card, Information foraging., Psychological Review 106 (1999) 643–675. doi:10.1037/0033-295X.106.4.643.
[28] C. C. Kuhlthau, Inside the search process: Information seeking from the user's perspective, Journal of the American Society for Information Science 42 (1991) 361–371.
[29] D. Ellis, A behavioural model for information retrieval system design, Journal of Information Science 15 (1989) 237–247. doi:10.1177/016555158901500406.
[30] G. Marchionini, Information Seeking in Electronic Environments, first ed., Cambridge University Press, 1995. doi:10.1017/CBO9780511626388.
[31] N. J. Belkin, Intelligent Information Retrieval: Whose Intelligence?, in: W. D. Rauch, F. Strohmeier, H. Hiller, C. Schlögl (Eds.), Herausforderungen an Die Informationswirtschaft: Informationsverdichtung, - Informationsbewertung Und Datenvisualisierung: Proceedings Des 5. Internationalen Symposiums Für Informationswissenschaft, ISI 1996,

Berlin, Germany, October 17-19, 1996, volume 27 of *Schriften Zur Informationswissenschaft*, Hochschulverband für Informationswissenschaft, 1996, pp. 25–32.

[32] T. Saracevic, The Stratified Model of Information Retrieval Interaction: Extension and Applications, Proceedings of the ASIST Annual Meeting 34 (1997) 313–27.

[33] Doug A. Bowman, 3D User Interfaces, in: The Encyclopedia of Human-Computer Interaction, second ed., 2013.

[34] M. A. Kilian, Where to Go and What to Do: Towards Understanding Task-Based Information Behavior at Transitional Spaces, in: Proceedings of the 2019 Conference on Human Information Interaction and Retrieval, ACM, Glasgow Scotland UK, 2019, pp. 413–416. doi:10.1145/3295750.3298972.

[35] D. Kelly, Methods for Evaluating Interactive Information Retrieval Systems with Users, Foundations and Trends® in Information Retrieval 3 (2009) 1–224. doi:10.1561/1500000012.

[36] A. Duane, C. Gurrin, Baseline Analysis of a Conventional and Virtual Reality Lifelog Retrieval System, in: Y. M. Ro, W.-H. Cheng, J. Kim, W.-T. Chu, P. Cui, J.-W. Choi, M.-C. Hu, W. De Neve (Eds.), MultiMedia Modeling, volume 11962, Springer International Publishing, Bangkok, Thailand, 2020, pp. 412–423. doi:10.1007/978-3-030-37734-2_34.

[37] D. Giunchi, S. james, D. Degraen, A. Steed, Mixing realities for sketch retrieval in Virtual Reality, in: VRCAI '19: The 17th International Conference on Virtual-Reality Continuum and Its Applications in Industry, 2019, pp. 1–2. arXiv:1910.11637.

[38] L. Alfaro, R. Linares, J. Herrera, Scientific Articles Exploration System Model based in Immersive Virtual Reality and Natural Language Processing Techniques, International Journal of Advanced Computer Science and Applications 9 (2018). doi:10.14569/IJACSA.2018.090736.

[39] T. Teo, M. Norman, M. Adcock, B. H. Thomas, Data fragment: Virtual reality for viewing and querying large image sets, in: 2017 IEEE Virtual Reality (VR), IEEE, Los Angeles, CA, 2017, pp. 327–328. doi:10.1109/VR.2017.7892309.

[40] R. Linares, J. Herrera, L. Alfaro, AliciaVR: Exploration of scientific articles in an immersive virtual environment with natural user interfaces, in: 2016 IEEE Ecuador Technical Chapters Meeting (ETCM), IEEE, Guayaquil, 2016, pp. 1–6. doi:10.1109/ETCM.2016.7750829.

[41] S. B. N. V. Martins, Air-Sketching for Object Retrieval, 2015.

[42] W. A. Edmonds, T. D. Kennedy, Chapter 18 | Exploratory-Sequential Approach, in: An Applied Guide to Research Designs: Quantitative, Qualitative, and Mixed Methods, SAGE Publications, Inc, 2455 Teller Road, Thousand Oaks California 91320, 2017. doi:10.4135/9781071802779.

[43] J. W. Creswell, J. D. Creswell, Chapter 10 Mixed Methods Procedures, in: Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, fifth edition ed., SAGE, Los Angeles, 2018.

[44] E. Krokos, C. Plaisant, A. Varshney, Virtual memory palaces: Immersion aids recall, Virtual Reality 23 (2019) 1–15. doi:10.1007/s10055-018-0346-3.

[45] R. Fidel, Approaches to investigating information interaction and behaviour, in: I. Ruthven, D. Kelly (Eds.), Interactive Information Seeking, Behaviour and Retrieval, first ed., Facet, 2013, pp. 61–76. doi:10.29085/9781856049740.006.