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Movement in Virtual Time: How Virtual Reality Can Support Long-Term Thinking

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The immersive nature of virtual reality (VR) allows even complex information to be communicated in an engaging, interactive, and fast way. This is particularly useful in the case of long-term political processes, such as the siting, construction, and management of a repository for high-level radioactive waste (HLRW). In this paper, we present an approach to convey an understanding of such long-time horizons by converting the information into a motion-controlled VR application. To gain insight into how users experience a period of 500 years, a pilot study with 15 subjects was conducted. The first results were positive; the subjects were thrilled with the presentation format in VR and offered several recommendations for improvement of the time visualization. For inexperienced users, the interaction was possible without any assistance and has the potential to be adapted to other use cases.

CCS Concepts: • **Human-centered computing** → **Virtual reality**.

Additional Key Words and Phrases: virtual reality, timeline, data visualization, radioactive waste

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1 INTRODUCTION

Within the realm of politics, certain topics and decisions entail challenges that have far-reaching implications over extended periods of time, such as the pressing issue of climate change or the final storage of high-level radioactive waste (HLRW). HLRW disposal is a project of long-term governance, as it involves decades and centuries of active management, monitoring, knowledge transfer, and decision-making. Informed and committed citizens are a prerequisite for the success of this long-term project [4]. To discuss these topics efficiently, it is relevant to provide the involved parties with an understanding of the time scales associated with the respective problem. Most information materials use graphics or timelines for this purpose. These usually give a good overview of all relevant events and the order in which they are expected to occur. Timelines do not necessarily have to consist of horizontal lines. Various visualization options exist, from radial to grid to arbitrary representations [7]. However, it is difficult to convey through such a static graphic what it means to look at a problem whose time horizon is longer than our entire lifespan.

In recent years, virtual reality (VR) technology has evolved rapidly and offers the opportunity to create applications that can deliver information in an immersive way. VR is characterized by immersion, i.e., the degree to which the user is isolated from the real world, and presence, i.e., the psychological feeling of actually being in the virtual world [15]. Entering a virtual reality allows to experience data and facts differently than in 2D on paper or a screen [17]. VR is used in various contexts to convey information and is also successfully used for political communication [20], such as displaying election content and thus influencing the voting behavior of citizens [26] or generating awareness for refugee politics [22]. However, there are still open questions concerning political communication through VR [20].

The process of siting, constructing, and commissioning a repository for HLRW is currently in very different stages in various countries worldwide. Germany is currently engaged in a multi-step process of site selection. §1 of the German Act for selecting a site for a HLRW disposal facility [2] specifically addresses three time scales or points in time. The aim was to select a site by 2031[1], the radioactive waste should be recoverable for 500 years after the closure of the geological repository, and the facility should isolate the waste from the biosphere for one million years. Communicating such vastly different temporal dimensions presents several challenges and calls for a combination of textual/auditory, visual, and maybe artistic approaches [5].

In the past, a political top-down decision centering on a site in Gorleben generated substantial conflicts and controversies. The decision was criticized as unscientific and intransparent, ignoring citizens' criticism and concerns. As with other large-scale construction projects such as airports and train stations, it became evident that a siting decision could not be taken without public acceptance. Therefore, the current site-selection process requires public participation in the decision-making process [4]. Among the further attributes of the German site selection process, the relevant Act states that it should be transparent and learning [23]. Both goals require empowered citizens who can digest the information provided on the progress of the process and contribute to its improvement and adaptation.

A VR application was developed to make the time scales of HLRW disposal more intuitively understandable and tangible and to empower citizens to take part in long-term decision-making. Sound information presented in an accessible and graspable way is a prerequisite for meaningful participation concerning such a complex topic [8]. Accordingly, the following research questions were formulated: Can a VR application be employed to convey the time scales of HLRW disposal? And does the app stimulate thought processes about these long time scales?

2 RELATED WORK

Previously, the use of VR in nuclear waste management has mostly been limited to training staff, e.g., for dismantling and decommissioning nuclear facilities [10] or for operating a nuclear waste repository [13]. In recent years, however, national disposal companies such as the German BGE (Bundesgesellschaft für Endlagerung - Federal Company for Radioactive Waste Disposal) and the Swiss Nagra (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle - National Cooperative for the Disposal of Radioactive Waste) have started to use VR for familiarizing the public with the processes and (in the case of Nagra) with the timescales of the geological disposal of nuclear waste [6, 19].

In an on-site information center, the BGE offers a virtual-reality tour of the Konrad mine, where Germany's first repository for low- and intermediate-level radioactive waste is currently under construction [6]. In Nagra's visitor center in Leibstadt, a VR application facilitates 'time travel' into the future of the projected Swiss deep geological repository for up to 60,000 years [19]. While in the BGE application, users can actively choose which area to virtually visit next (selecting an icon transports them there), the Nagra application only allows users to look around and not influence the speed or the course of the VR experience.

[1]In November 2022, the relevant institutions announced that the German site selection process would take longer than that. Site selection is now projected to be completed between 2046 and 2068[4]

Previous studies have shown that the use of VR affects time perception, leading to a phenomenon called time compression [21]. An example shows that subjects have difficulty correctly estimating an interval of five minutes in VR when comparing two virtual settings on the computer and in VR [18]. This phenomenon could possibly be exploited to convey information better that extends far into the future.

Timelines are a classic way to visualize data that are related in time [7]. Fouché et al. [12] showed that 3D timelines visualizing data points in a virtual space around the user performed significantly better than a classic view where data could be selected by time.

In education, VR has been successfully used to teach history. The use of VR in the classroom has, for example, increased student motivation and learning outcomes [25]. In museums, VR is used to present historical research to the public and to stimulate discussion and engagement. It is essential to keep the usability as simple as possible to minimize the need for museum staff [9].

However, the immersive presentation of non-fiction content might lower focused attention and recall of information, partly because users explore the virtual environment while listening to the voice-over [3]. For instance, the possibility to look in any direction in the 360°-video might distract users from the information which is presented. This effect is even more pronounced in first-time users of VR headsets [16].

Furthermore, VR can help to convey geological information. For example, the VR movie Genesis shows how the perception of very long periods of time can be conveyed [11]. In the movie, the story of the formation of the earth and the evolution of life is told. The viewer is positioned on a giant clock, on which the entire period of 4.7 billion years continues to run while the story unfolds around them.

Another example is the Deep Time Walk smartphone app [1]. The app also illustrates the formation of the earth and the biosphere. Unlike the Genesis movie, it does not rely on the immersive power of VR but illustrates time via movement in the real world. With this app, users can go on a 4.6 km walk through the earth's history, accompanied by audio combining scientific information with a poetic approach. One meter of this walk in a location of the users' choice equates to one million years of earth's history. Starting 4.6 billion years ago, this deep time walk clearly shows the dearth of narratable events during the first few kilometers and a rapid succession of milestones during the last 500 meters. Looking into the future of HLRW disposal presents a similar problem of scale, with most events happening in the next few centuries and a long-term horizon of one million years of safe storage.

Both the movie and the smartphone app served as inspiration for this work. The immersive possibilities of a VR environment, as well as the potential of an application that uses motion to make the relationship between time horizons tangible, are used in this application. The following chapter describes how these two approaches were combined and transferred to the context of HLRW disposal with a view into the future.

3 METHOD

To convey information about the very long-time horizons involved in siting, constructing, and managing a final repository for the disposal of HLRW, a VR application was designed to give the user as much freedom as possible to envision the future. A VR space was designed to place relevant information in temporal relation, primarily to give the user a sense of the length of time being observed. The virtual space consists of a large clock face with a radius of 2 meters, in the center of which the user stands. A night sky is visible around the clock. The clock has a large hand aligned at 12 o'clock when the application is launched. A screenshot of the start screen where the clock hand points at 2023 is shown in Figure 1.

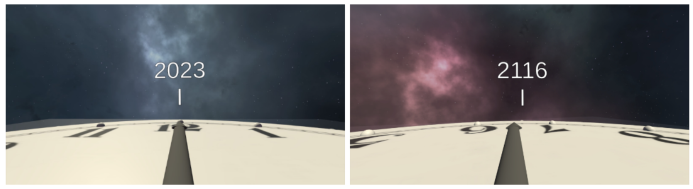

Fig. 1. Screenshots showing the clock and the years 2023 and 2116 © Paula Bräuer

Fig. 2. Timeline showing events relevant to the disposal of high-level radioactive waste in Germany © Paula Bräuer

The hand rotates according to the rotational movement of the user. One full turn corresponds to 60 years. As we wanted to show all relevant events over the next 600 years in the correct temporal relation, 60 years was chosen to keep the number of rotations within reasonable bounds while still maintaining enough distance between the individual events to make the passage of time tangible. Various points relevant to the context of site selection, repository construction, and management are marked along the dial. When the hand reaches one of these points, it stops. The year in which the event is expected to take place is then displayed, and an information text about the event is recited. Including the start information, seven such events are triggered. Figure 2 shows the events on a timeline. Following an optimistic trajectory, we located site selection in 2046 and all subsequent events accordingly, following current estimates.

The penultimate event describes the time 500 years after repository closure (approx. 600 years from now). After that, the last event is triggered at the full hour, informing the user that one would have to look up to one million years into the future (at which time the HLRW would no longer be harmful to the biosphere). To reach the event 600 years in the future, the user has already completed nine full turns. To see one million years into the future, our conversion rate would require more than 16,000 additional turns, which would take a very long time and cause discomfort to the user, and was therefore not implemented. The time it takes for the user to experience the VR application depends on the speed at which the individual is spinning. At a medium rotation speed, the entire experience takes about five minutes.

The potential user group of the application will include random citizens interested in the topic, researchers from a wide range of disciplines, and employees of various authorities and NGOs. To provide users with little or no experience with using VR headsets and handheld controllers, an interactive experience without a lengthy introduction to the hardware, alternatives for control and interaction in VR were sought. In addition to today's typical handheld controllers, the user's movements can also be used to interact with an application [14]. Therefore, we chose motion control to make our application as easy to use as possible.

4 PILOT STUDY

An exploratory pilot study was conducted to answer our research questions and to get a general impression of the usability of the VR application. The study was conducted in March 2023 as part of a project event. Attendees could visit a booth to learn about the time horizons of radioactive waste disposal and, if interested, test the VR application and then fill out a questionnaire. The subjects were individually led to a designated area where they were given a PICO 4 headset that launched the application.

The VR application was tested on 15 subjects with a broad knowledge of the HLRW disposal process. Ten subjects were from academia, and five were from the public. Ages ranged from 24 to 62 years; six subjects were female, and nine were male. Only four subjects had some VR experience, and the rest had none. A total of 11 subjects (73 %) answered the survey.

The general verbal feedback on the VR application was very positive. Probably due to the novelty effect, some users were excited about this new way of visualizing information. Usability also proved to be straightforward. All users were able to use the application intuitively. It was only during the very long period between the events in 2116 and 2616 that some users were unsure whether the application was finished or if there was more to come.

The survey comprised two questions that subjects could complete after the VR application test: 1) How would you attempt to make the timescale of 500 years graspable? 2) Do you have any further thoughts on the time scales of radioactive waste disposal?

Concerning the first question, most subjects suggested a comparative approach. While one subject only mentioned "comparisons" without a particular qualifier and another had the idea to use the decay times of materials such as plastic, the majority of suggestions (n=7) concerned looking into the past and using the last 500 years of human history in order to make the 500-year horizon of the recoverability period more tangible. Answers included "projecting human history backwards" or looking at the year 1520 and outlining the historical developments since then. Another subject specifically suggested using the history of the Protestant Church for comparison, starting with Reformation in 1517. Finally, two answers referred unspecifically to "visualizations".

Since this study was exploratory, the second question was deliberately broad to collect diverse possible answers and suggestions. Therefore, only one answer specifically addressed the further development of the VR application, suggesting the additional use of music. Other comments (n=4) addressed recent changes in Germany's site selection schedule and expressed subjects' concerns or hopes for the effects of these changes. The other subjects did not answer this question or used it to express their interest in the topic.

5 DISCUSSION, FUTURE RESEARCH, AND LIMITATIONS

The pilot study addressed the research questions concerning VR and the conveyance of long time horizons. Subjects could use the application quickly and without assistance, which is in line with recommendations for implementing VR applications [9]. Since the application is operated by rotating one's own body on the spot and too many rotations could cause dizziness, choosing a time conversion rate from years to clock rotations was a challenge. At the same time, it had to be recognized that the relevant events do not occur uniformly over a million years. This challenge is similar to deep time applications that map the geological past [1, 11]. The challenge in both cases, e.g., deep time applications and looking into the future of final disposal, is that the further you get from the present, the fewer known events there are. This means that many events accumulate early in the timeline and then become fewer. However, the scaling seems to have been chosen appropriately, as none of the subjects felt sick. A few subjects mentioned that it could have happened with further rotations. We, therefore, recommend not to exceed approx. 10 rotations.

Users of our VR application can determine the speed of their experience of the upcoming centuries of HLRW disposal (if they do not move, nothing happens), and actively trigger the progression of this experience by moving their bodies. Real locomotion in a virtual environment (as opposed to, e.g., using a pointer) facilitates better immersion and subjective presence [24] and enhances memory [27] of the virtual experiences. Making the users of our application turn in a circle to move the clock hand forward should thus help them to understand better and remember the time scales involved. However, further comparative studies have to be done to test this assumption.

The implementation of interaction without a handheld controller, just by the user's movement, proved successful in the study. All subjects were able to use the application immediately without any prior instruction. Unlike, for example, a VR movie, our application does not run automatically but is driven by the user's movements at an individual speed. In this way, even inexperienced users are not overwhelmed by the VR environment. A transfer of the study setting to other contexts where information will be presented interactively with VR seems reasonable.

One limitation in testing the application was that the PICO 4 headsets' speakers were not loud enough in the test environment. The study was initially conducted behind a booth in a large room full of people. Since all the information, except the year numbers, was audio and was difficult to understand, the location was changed to a quiet place after the first subject. Nevertheless, there is no evidence that the noise negatively affected the study results. However, a quiet environment or the option of using headphones is recommended. Another consideration to examine is the extent to which users' attention is diverted from the voice-over by exploring the virtual environment [3, 16]. Another limitation of the pilot study is the strong focus on the design of the application. Factors such as enjoyment or usability could have been included in the survey to provide quantifiable data and further explore the impact of the VR application on participants' perceptions. It would also have been interesting to examine how the VR application affected their perceptions or attitudes toward the disposal of HLRW.

One aspect that could be considered for further application development is incorporating temporal references to the past. As seen in the survey results, using references to past events can help in understanding long periods of time. Two possible approaches to addressing this issue are planned for further investigation. One possibility would be to allow the user to turn not only clockwise but also counterclockwise. This would allow experiencing both the future and the past. In this approach, the user's movement, i.e., the rotation around its own axis, would clarify the understanding of time. Alternatively, it would be possible to visualize both time axes in parallel. The user could be presented with a historical reference event for each future event. Another issue that might be included in a more elaborate version is the depiction of alternative paths and scenarios which might occur in the future of HLRW disposal. However, in creating more visually complex versions, the potential trade-off between increased immersion and decreased retention of information should be borne in mind [3].

This pilot study addressed users already well acquainted with HLRW disposal. A more elaborate version of the audio explanations could be developed in the future to make the application more accessible to people with no or very little prior knowledge of the subject. Alternatively, to avoid cognitive overload in the VR environment, additional information might be provided in supplementary material, such as posters/handouts or an introductory presentation.

6 CONCLUSION

Conceptualizing and communicating the timescales of radioactive waste disposal is a challenge. Therefore, developing tools to enhance public understanding of different time scales will be an important contribution to facilitating long-term governance for radioactive waste disposal. The VR approach presented in this paper, which combines body movement and topical information concerning timescales, is a first step towards a more creative and immersive approach to conceptualizing the temporality of such long-term projects. Our pilot study yielded very promising results. Verbal user feedback on experiencing the time scales of HLRW disposal through motion in a VR environment was very positive. Responses to our survey provided helpful suggestions for further improving the application, particularly concerning comparisons with the past 500 years of human history. A more elaborate study will be designed to implement these suggestions and to compare the VR experience of time using locomotion against other options (such as using controllers or a desktop application).

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