

Towards an Experiment Planner for Cognitive Studies in Virtual Heritage Environments. A Pilot Study.

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Abstract

The increasing role of Virtual Reality in psychology introduces new methods for replicable experiments and enhances techniques for analysing human behaviours. Despite the technological advancements, a flexible and user-friendly approach for researchers and psychologists is still lacking, making it challenging to meet their specific needs and requirements. This paper describes the design, development and testing of a prototype for configuring and managing experiments in virtual sessions in cultural 3D spaces. The prototype represents the first version of a future tool dedicated to the planning of assessment sessions in Virtual Heritage environments. To test this prototype we have used the Digital Twin of a physical Exhibition dedicated to Aldrovandi.

CCS Concepts

• *Applied computing* → *Psychology; Arts and humanities*; • *Human-centered computing* → *Virtual reality*;

1. Introduction and Methodology

Does the way we spatially explore museums and exhibitions impact how we appreciate and understand them? In psychology, it is well known how human beings have three distinct navigation styles - namely, landmark-style (LS), route-style (RS), and survey-style (SS) users, which correspond to different levels of navigational skills [PDB01] - and their influence on sense of direction has been demonstrated [BGP*18]. It is therefore possible that they also have a similar impact on spatial orientation and spatial memory, which could eventually have an impact on museums' visits. In this case, cultural institutions and designers would need appropriate physical and digital tools (e.g., improving wayfinding techniques [Gib09] and visual displays) to enhance museum's experience, taking into account visitors' attitude. It is crucial to verify this assumption to be able to identify proper solutions.

How can we experimentally verify it? Can we use the 3d digital version of an exhibition (digital twin) as a high-fidelity replica of reality and as an experimental environment? How can we control an experiment, the needed observations, the tasks required to be carried out by participants in such an environment? How required settings and features can be configured in order to control, observe, and record such a virtual environment, addressing the research objectives? In the next sessions we will describe a possible solution for the design and management (conduction) of user-testing experimental sessions gathering relevant physio-psychological data,

paving the way for a future web-based service ("Experimental Planner") dedicated to Digital Heritage, in line with the objectives of the PERCEIVE and H2IOSC projects.

The above mentioned questions arise from the established practice in cognitive sciences, where VR settings are now commonly used to conduct experimental activities, demonstrating that 3D immersive environments can effectively simulate real-world contexts [SKF22] [BNAJ*20] [RBB*16]. However, in the field of Cultural Heritage, their use remains significantly limited, due mainly to the lack of suitable features in existing tools. Furthermore, current solutions do not present enough flexibility and usability without coding expertise [RYS*19]. Currently, these limitations restrict the ability to set experimental variables, modify setups and environments, according to specific research needs.

Therefore, in the context of CHANGES project (Spoke 4 - Virtual Technologies for Museum and Art Collections) [BBB*24], we have set a team composed by psychologists, designers, and digital heritage experts with the objective of: a) collecting the needs and requirements for defining features suitable for capturing users' behaviours in 3D and VR environments; b) developing a first prototype with such features applied to a psychological experiment (i.e. the analysis of navigation styles and spatial orientation in the context of a museum or exhibition); c) testing the prototype with a group of psychologists, acting as "operators" in laboratory sessions with real users; d) analyse the results to improve the usability and fea-

tures of the prototype and to extend its use beyond the pilot phase. We have also identified an optimal case study for the prototype: the 3d digital twin of the temporary exhibition *The Other Renaissance: Ulisse Aldrovandi and the Wonders of the World*, held in Bologna between 2022 and 2023 [BBB*24]. To optimise the experiment, we decided to use only the first two rooms of this virtual exhibition.

After having considered available studies (Sect. 2), we have organised interviews with experts in cognitive science to gather commonly adopted practices in experimental psychology and to identify needs (Sect. 3). The results were used to define the requirements, set a methodology and develop the prototype (Sect. 4). Finally we have carried out 19 experimental sessions to test the use of the prototype (Sect. 5), the effectiveness of the UX/UI, errors occurrences and learning curve (Sect. 6).

2. State of the Art

Psychology has witnessed a surge in the exploitation of VR and MR due to their ability to provide safe spaces for patients, reproduce high-fidelity environments, and offer precise control over stimuli in order to avoid extraneous factors or unchecked conditions that may influence users' performance [SKF22] [BNAJ*20] [RBB*16]. As a result, they have proven to be ideal for the study of dynamic human behaviours, making them extremely valuable not only for treatment and training, but also for research. However, the success of this technology varies across these areas, with more applications evident in the first two fields [CSLC*19] [RCGS*18] [DPLD20] [JSO*21]. These examples are usually standalone, finished products designed for and with specific functions, therefore lacking the flexibility and features necessary for research. Indeed, experiments demand the manipulation of a complex array of variables, including customisable VR assets, environments and interactions, collaborative or multi-user sessions, seamless data management and analysis, hardware and software compatibility, and so forth. Nevertheless, in order to achieve this degree of adaptability, it is either necessary to use an authoring tool or to possess the requisite programming and game development skills which psychology researchers usually lack [RYS*19].

The development of experimental frameworks for traditional screen-based paradigms has yielded a plethora of examples over the past few decades. However, a recent review by Bridges et al. [BPMP20] has indicated that only Psychtoolbox [Bra97] [KBP*07] and PsychoPy [Pei07] currently support VR - albeit still in development and both requiring programming skills in MATLAB and Python respectively. In parallel, a number of recent add-ons have been developed for the purpose of conducting behavioural experiments using major game engines. These include bmlTUX [BT20] and UXF [BWA*20] for Unity. UXF, in particular, includes a comprehensive set of C# classes for the control of trial-based experiment flow and the collection of behavioural data, designed to address the specific requirements of researchers. It should be noted, however, that these integrations on such engines still require certain programming and game development skills. In response to the discrepancy between the limited functionalities of traditional screen-based tools and more sophisticated customisation for game engines, innovative softwares, such as Vizard (<https://www.worldviz.com/releases/vizard-7>)

and Navwell [CDC*20], have emerged in recent years. Both platforms provide specialised solutions for this research area. Vizard, in particular, is notable for its user-friendly approach, with Python as scripting language, and a suite of prebuilt modular example scripts and powerful integrations, such as SightLabVR Pro (<https://www.worldviz.com/virtual-reality-eye-tracking-for-research-solutions>) and vexptoolbox [SKF22]. Navwell, alternatively, provides prebuilt virtual reality environments that have been specifically designed to meet the requirements of certain psychological research tasks. However, both platforms exhibit certain limitations. For instance, they offer basic built-in analysis tools that may require data export for more advanced analysis software or paid add-ons. Furthermore, collaborative research environments are currently supported only by Vizard. In conclusion, our analysis of VR tools for psychological research demonstrates that while significant progress has been made towards more suitable solutions, there is still room for improvement to enhance the usability and flexibility of such software, in order to fully meet the unique requirements of researchers within this field. In conclusion, our analysis of VR tools for psychological research demonstrates that while significant progress has been made towards more suitable solutions, there is still room for improvement to enhance the usability and flexibility of such software, in order to fully meet the unique requirements of researchers within this field. A similar situation can be observed with regard to digital heritage, where no ready-made tools have yet been developed in this sense. Nevertheless, there is a potential avenue for progress in the form of ATON (<https://osiris.itabc.cnr.it/aton/>) [FFD*21] with its recently integrated plug-in, Merkhel [FG24]. Moreover, it is also noteworthy that within this tool, the use of immersive VR setups has been employed as prototypes for evaluating the reliability and usability of virtual museums in real spaces [PDFF18], albeit not yet formalised for experimental purposes.

3. Needs and Requirements

To better identify the needs of our potential users (i.e. psychologists, professionals in social sciences, but also designers), we have organised interviews with the goal of specifying the commonly adopted workflow when setting and conducting an experiment. Currently, experiments in social science and psychology start with the definition of research questions, the selection of the most appropriate methodology, and the identification of variables for analysis under specific conditions. These variables are organised into a matrix, tasks are designed accordingly and assigned to groups of testers. A protocol is set and followed by all evaluators / operators in the same identical way, ensuring the replicability of the experiment and the consistency of results.

From these interviews we have collected the following requirements: 1) ensure the capability to administer questionnaires both before and after sessions, independently of the experimental session itself; 2) provide a 3D interactive environment explorable through desktop and VR platforms; 3) configure tasks with variable instructions, based on the experimental conditions; 4) precisely measure time intervals, such as the tasks' duration; 5) offer intuitive tools to observe and intervene in real-time on the tester's

conditions, such as showing images, displaying 3D objects, playing audio tracks or moving tester's position; 6) facilitate the configuration of each experimental session to allow for systematic comparison of setup variations; 7) properly collect relevant data throughout the experiment to ensure analysis and interpretation; 8) ensuring a full variable control in the virtual experimental environment.

These requirements have been then aligned with the DEAR principles [Gru23], which advocate for Design, Experiment, Analyse, and Reproduce. This approach allowed us not only to address existing gaps in current tools but also to better support every facet of the experimental lifecycle, as illustrated in the following schema (Fig. 1).



Figure 1: A methodology for VR and hybrid experiments.

This schema describes the relevant stages involved in an ideal experimental process. Our prototype would initially be focused on the “conduction stage”, while only after its assessment, where we would collect technical and usability data, it will be extended to cover also the other stages.

4. Early Prototype Design and Development

Considering the above mentioned requirements, a first UI/UX design has been carried out and a functional prototype has been developed integrating a set of features suitable for properly conducting an experiment session. A web-based application has been designed, to minimise as much as possible hardware and software complexity with a locally installed setup. These technological requirements are met by the framework ATON [FFD*21], an open source solution specifically designed to manage 3d, immersive and multi-user environments in web applications for Cultural Heritage. Our prototype consists of a module capable of wrapping an existing ATON-based web application (the environment) and providing the operator (psychologist) with an admin panel to control the environment and the user's actions (tester) within a multi-user session.

The admin panel is designed as a straightforward step-by-step wizard that facilitates both the initial configuration of the session's conditions and the state's management during the experiment. In both desktop and VR platforms, the tool allows real-time observation of the tester's movements, enabling the operator to freely orbit around, without being seen. The operator can easily manipulate the tester's state, by moving the tester in a specific spatial location; displaying a set of predefined images or objects in the 3d space; playing audio tracks at specific moments; assigning specific tasks to the tester; recording tasks duration and success. All these functions are accessible through buttons arranged in a linear and logical order that follows the experimental workflow and protocol (see Fig. 2).

To be able to assess the prototype in a real setting, we have adopted as a 3D environment the ATON-based digital twin of the Aldrovandi exhibition. This choice meets the following set criteria:



Figure 2: Screenshot of the VE (in ATON) with the admin panel.

a 3d reconstruction of a museum space subdivided in more than one room; a number of heterogeneous exhibited artworks, individually labelled; a realistic rendering of the environment and of the objects. These criteria were needed to enable testers to perform tasks such as observation, memorisation, recall and search.

5. Testing on Aldrovandi Digital Twin

After the development, we have tested the prototype as explained, to better understand usability, errors and learning curve, with the goal of improving the final and future application. The assessment was conducted in 19 experimental sessions (with 19 end-users) by three 24-years-old practitioners in psychology, whose goal was to examine how navigational styles influence appreciation of the virtual heritage experiences. The results of this specific experiment will be in depth discussed in a future publication, when the complete set of data will be collected and analysed. These practitioners have been set as “subjects” of our testing. During the sessions, we employed a “formative user testing” approach [KZLL22] [HAW01] aimed at identifying UI/UX design issues and providing solutions, even in case of small groups of subjects.

Regarding usability, we have directly observed the behaviours of the subjects using the prototype [KZLL22]. Errors have been specifically recorded. The 19 sessions have been divided into three phases, to better explore how the same subjects were learning how to use the prototype (learning curve) in a simulation session at the beginning (Time 1 - T1), in real sessions after one day (T2) and after one week (T3). This temporal analysis was crucial to validate design decisions and define priorities for future redesign [VL23] [LS21] [Ran24]. Before starting the sessions, all subjects received the same brief training about the admin panel and the setup procedures. Each subject was asked to conduct experiments using both the desktop and VR version of the prototype.

We have documented observations in an online form, where we have tracked: subjects' difficulties, comments, errors and time spent. We categorised errors in two groups: explicit (E1) and implicit (E2). E1 included errors made using the UI that may interrupt the linearity of the experiment (e.g. technical set-up, wrong selection of a button). E2 were not directly depending on the UI, but were impacting data acquisitions (e.g. missing full-screen setting for desktop, not starting screen recording in time). Errors have been categorised into three severity levels based on their impact on time delay or potential data loss, described by a coefficient: 1 for minor, 2 for moderate, and 3 for severe errors. A global Error Index (ϵ) for



Figure 3: Observation of a subject conducting a VR session.

each session is calculated by summing the products of the number of errors at each severity level and their respective coefficients.

After the assessment, each subject was required to fill the System Usability Scale (SUS) questionnaire [Lew18]. Then, a focus group session was organised to gather further insights and comments about the prototype. The focus group was moderated and documented with Miro (<https://miro.com/it/>).

6. Results and Discussion

All subjects have successfully completed all sessions. More specifically, the resulting data shows a decreasing amount of subjects' errors over time. We have represented the learning curve (Fig. 4) by showing the evolution of the errors. The average Error Index (ϵ) decreases over time, showing this positive, but slow, learning progress in all subjects. The higher frequency of explicit errors ($\epsilon 1$) highlights critical issues in the UI. These results are consistent with the SUS questionnaire, which reported a usability scale of 63.33 out of 100, slightly below an accepted average (68) [Lew18].

Subject's observations and comments acquired with the focus group were crucial in defining which are the main usability limits of the prototype. We have identified the following weaknesses that will be addressed in the redesign: a) the admin panel was not always perceived as intuitive nor linear, b) cognitive overload and c) lack of familiarity with the technological set-up (setting of a local network and of the VR headset). To address these issues, solutions include the improvement of the user flow and of the admin panel interface. On the one hand, the analysis of $\epsilon 1$ suggests the possible UI improvements: assign a panel to each of the steps in which a session is subdivided, grouping different buttons; improving feedback on the current state; adding undo-redo features. On the other hand, the results of $\epsilon 2$ emphasise the need to automatise the manual procedures which are currently required for the correct setup of the prototype. This implementation may positively impact cognitive overload as well.

In conclusion, the assessment allowed us to gather the necessary elements for redesigning the prototype, to better specify the requirements, and to lay the foundation for developing a tool that will include other experimental stages in the future (see fig.1). Moreover, we plan to integrate the functionalities of Merkhel, empowering the analytics features. Finally, we foreseen developing a web-service supporting the setting and customisation of experiments in

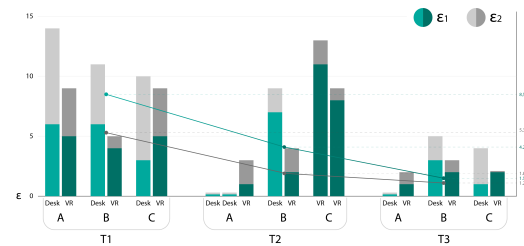


Figure 4: Representation of the recorded decreasing evolution of errors with implicit and explicit tasks ($\epsilon 1$ and $\epsilon 2$).

the field of digital heritage. As a further conclusion, we have also proved how the creation and reuse of digital twins are crucial for the future of Digital Cultural Heritage, and particularly useful in iterative design and assessment process.

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