INTEGRATING IMMERSIVE VIRTUAL ENVIRONMENT USER STUDIES INTO ARCHITECTURAL DESIGN PRACTICE: A PRE-OCCUPANCY USER STUDY OF TRAIN STATION WAITING PREFERENCES WITH VREVAL

Grayson Bailey
Olaf Kammler
René Weiser
Sven Schneider
Ekaterina Fuchkina

Bauhaus-Universität Weimar
Belvederer Allee 1, 99423 Weimar, GERMANY

{grayson.daniel.bailey, olaf.kammler, rene.weiser,
 sven.schneider, ekaterina.fuchkina}@uni-weimar.de

ABSTRACT

User-centered studies in Immersive Virtual Environments (IVEs) are able to provide valuable feedback in the form of Pre-Occupancy Evaluations (Pr-OEs). Pr-OEs allow for immersive design reviews of architectural space before construction is complete, thus providing better opportunities for user-centered values to be appraised and addressed by designers. If integrated into the architectural design process, Pr-OEs can also aid in design development by comparing participant responses to multiple design variations.

In this paper we present the further development of VREVAL, a framework for performing user studies in IVEs, and a case study of its application in the study of waiting preferences. An overview of the VREVAL web platform and desktop application explain the modular study components within a BIM workflow. An example study showcases the VREVAL “Placing” module while examining participant waiting preferences in four alternative designs for a train station building in Germany.

Keywords: immersive virtual environment, architectural user study, waiting preference, Pre-Occupancy Evaluation.

1 INTRODUCTION

The use of Immersive Virtual Environments (IVEs) to perform user studies on architectural spaces has become more popular in the last few years, especially on the subject of emergency wayfinding (Natapov et al 2022, Irshad et al 2021). Such user studies allow for researchers and architects to understand qualitative user responses which cannot be calculated, such as conditional preferences, real behavioral performances and other participant responses to spatial experience. Previously, user studies were mainly performed as Post-Occupancy Evaluations (POEs), which take place after the building is completed and in use. Today, IVEs and related technologies allow for user studies to take place as Pre-Occupancy Evaluations (PrOEs), which can integrate into the architectural design process.
Performing PrOE s during early design phases, especially during schematic design, also allows for the evaluation of multiple design options and the selection of a design option based on specific data-driven feedback. PrOEs have largely focused on the user interaction with digital mock-ups (Dunston et al 2011, Crescenzio et al 2021), the comparison of user spatial ratings of interiors (Fisher-Gewirtzman et al 2019), and the wayfinding behavior of users under different conditions (Natapov et al 2022, Irshad et al 2021).

However, there remain challenges which the organization of IVE studies must face, such as (1) providing a general framework for customizable study design and execution, (2) easy implementation for researchers and participants, (3) use of common research methods, and (4) ability for sharing full study structure and environments (Wölfel et al 2021).

Several frameworks for IVE-based architectural research have been designed to address these various challenges (Grübel et al 2017; Moloney et al. 2019; Agirachman and Shinozaki 2021), and common research methods for wayfinding have been thoroughly developed, although there remains a lack of a flexible multi-purpose study framework. Previously, VREVAL has been presented as a framework for a range of user study focuses in IVEs (Schneider et al 2017), and has demonstrated the ability to combine questionnaires, spatial ratings, and participant tracking in a robust framework. However, VREVAL was also limited by the same issues of implementation ease, flexibility of study design, and ease of accessibility. In further developing the VREVAL framework, effort has been made to construct a more modular, centrally accessible, and easily integrated framework into commonly used Computer-Aided Architectural Design (CAAD) and Building Information Modelling (BIM) methods for research study design.

In this paper, we present a technical overview of VREVAL in the form of a web platform and desktop application, and contextualize the framework by the showing the design and outcomes of an example study on train station waiting preferences. The description of VREVAL developments focus on the simplified access via the web platform for researchers, the modular study elements and process of study design, and the increased ease of study implementation and review. Integration with usual CAAD and BIM practices will also be shown via the connection between study design, 3D modelling software, and results visualization with the VREVAL Dynamo package. The example study will focus on user waiting preferences in four design alternatives for a train station in Germany, combining both placing activities and questionnaires in order to compare two forms of participant-provided responses. Qualitative and quantitative outcomes from the study show VREVAL as not only a useful scientific tool, but also a useful design tool for comparing architectural alternatives.

2 VREVAL

The workflow of VREVAL integrates user studies within the architectural design process, as seen in Figure 1. From a basic digital model of an architectural or urban design project, VREVAL user studies can be designed to verify design parameters, test expected user behavior, and compare responses to multiple designs. Once the study is conducted, the outcomes are reintroduced into the developing the architectural or urban design project – either in the form of explicitly preferred design options, response data for comparison against computational methods like Accessibility and Visibility Graph Analysis (VGA), or the unveiling of further design problems which must be addressed.

Once a designer or researcher has a digital model, a new user study can be designed, administered, and reviewed with VREVAL using two basic interfaces: a web platform with three main functions (study design, administration, documentation), and a desktop application which also contains three functions (study design, module testing, evaluation). Within the desktop application, two modes of use allow for participants to perform user studies on a full range of devices. The Head-Mounted Display (HMD) Mode uses Virtual Reality (VR) headsets and accessories, such as the Oculus Quest 2, as display and interface devices, while the Monitor-Mouse-Keyboard (MMK) Mode allows for participation in studies without a VR headset or accessories.
The technical organization of VREVAL (Figure 2) centers on a database that stores study content, study administration and study results. Via the web platform, the researcher uploads digital models and audio sets and then organizes the study content into a sequenced set of experiences for the participant. Once a study is ready, the desktop application downloads the study assets (digital models, instructional prompts, etc.) and a participant performs tasks as specified by the researcher. Upon completion of each task, results are uploaded to the VREVAL database in order for partial data to be saved even under the conditions of early termination or participant cybersickness. Once the study is performed by the required number of participants, the full set of results and documentation can be downloaded from the web platform. Finally, these results can be further analyzed in statistical software and/or in 3D modelling software.

2.1 Study Content

In order to construct the study outlined above using VREVAL, there is a limited hierarchy of elements which must be organized by the researcher. As seen in Figure 3, “Study Content” are basic elements (Forms, Markers, Environment Bundles) at the base of the hierarchy, Organizational elements (Playlists, Scenarios, Tasks) arrange how and when the participant performs actions during the study, and Administration elements (Evaluation Groups, Sorting Questions, User Codes) help to conduct the study in a simple manner.

The three basic elements of Study Content are environment bundles (digital model and audio sets used in the IVE), markers (specific locations within the IVE), and forms (text-based information and questionnaires).

First of all, environment bundles contain all environmental data for the study (i.e. all 3d models of the context, the design for study, audio to be heard during the study, etc.). 3D Models and audio sources are first created via third party software (Autodesk Revit, Rhinoceros 3d, Audacity, etc.), and exported into Unity. In Unity, the researcher separates 3D Models into sets based on their relation (i.e. urban context, architectural design, scenery, etc.), which can be toggled within the study to differentiate which parts of the environment bundles are included at any given moment. From Unity, these sets of models are exported, zipped, and uploaded to the VREVAL web platform.
The second element of Study Content is a Marker, which represents a location in the IVE where an interactive action takes place. In VREVAL there are three types of Markers: checkpoints, info points, and gates. Checkpoints are Markers that are connected with goals of the study – locations where the participant starts a task, receives information about a task, or ends a task. Info points, in contrast, are markers that contain only warning information rather than task instructions, such as “go back to the Plaza to continue the study”. Finally, Gates are a type of Marker that transports the participant from one point in the IVE to another, simulating an elevator transporting the participant from one floor to another. Markers are placed by the researcher using the design function of the VREVAL desktop application in either HMD or MMK mode.

The final element of Study Content is the Form, which represents all text-based information provided to participants. Forms can contain task instructions, questions (single or multiple answer), semantic differentials, and can contain multiple pages for longer texts. The researcher organizes the content of Forms directly on the VREVAL web platform.

![VREVAL Element Hierarchy](image)

Figure 3: VREVAL Element Hierarchy.

### 2.2 Study Organization

Once the study content is provided by the researcher, the study organization is determined using the modular elements of Tasks, Scenarios and Playlists. First, Task modules specify the type of activity which will be performed by the participant, i.e. whether the participant will be placing a marker, providing annotation, travelling to waypoints, or choosing among design options. Additionally, each Task specifies settings for the user and environment, such as which environment bundles are included and how the user is able to move around the IVE. Within each Task, Markers and Forms are combined and Task-specific settings are chosen by the researcher, such as the waypoint locations during a Wayfinding Task or the number of placements during a Placing Task.

The second organizational element of VREVAL is the Scenario. A Scenario is a collection of related Task modules, and comprises a study section. Similarly, the third organizational element of VREVAL is the Playlist, and Playlists are collections of Scenarios. In this way, the Scenario acts as a section of the study and the Playlist determines in which order study sections are performed.

### 2.3 Study Administration

Once the study design is finished and the researcher has organized all elements in the VREVAL web platform, the researcher must provide evaluation settings before the user study is activated and open for participants. First, a “snap-shot” of the study is taken, making sure that no further changes are made to the study while activated. Then, in the case of studies with multiple possible Playlists, the researcher must determine Evaluation Groups which are linked with Playlists from the study. As an example, between-group studies would require multiple Evaluation Groups with different playlists that contained changes in
their respective Scenarios or Tasks. The researcher must then provide a Sorting Question in order to evenly distribute participants among the Evaluation Groups based on their answers.

Finally, once a user study is activated, unique User Codes are generated on the web platform. User Codes are provided by participants in order to start the study, and are able to individually identify participant sessions without betraying participant anonymity. While the study remains activated and after the study has concluded, a full set of results and other documentation can be downloaded from the web platform. In the following case study, we will describe the process of study design using VREVAL and how the framework was applied in order to examine train station waiting preferences in multiple designs.

3 CASE STUDY

The following case study examines user waiting preferences within four train station building designs for a small town in Germany. The Control option is the current construction on site, and three additional design alternatives (Option A, B, C) have been provided by architectural students at the Bauhaus-Universität Weimar. As seen in Figure 4, the four options differ in architectural form and services planning: Control has a single building on the western side of the site with covered waiting, Option A has three tight buildings framing a waiting area on the eastern side of the site, Option B has a single building on the eastern side of the site and covered waiting along Platform 1, and Option C has a three buildings aligned along the platform with covered waiting along Platform 1.

![Figure 4: Four design options studied.](image)

The goal of this case study is to document waiting location preferences in each design, compare these preferences in reference to architectural qualities, and query qualities of importance for user waiting experience. Waiting preferences are particularly important in the architectural design of transit buildings, as the behavior and preferences of users will determine the success of building services and commercial areas. User experience in train travel is usually most stressful for travelers’ while changing trains and waiting on travel connections (Van Hagen 2011, Van Hagen and Bron 2014), thus understanding the preferred waiting behavior of users is very relevant to the transit architecture. However, previous seating preference research has focused the correlation of seat location and educational performance (Gou et al 2018, Tunahan et al 2021), or seating choices and user profiles (Clark and Walker 2020). With combined questionnaires and placing tasks, the specific locations of waiting preference can now be documented with VREVAL, and thus provide direct locations of preference within architectural models.
In this study, waiting preference is examined for each of the design options with two methods, as seen in Figure 5. The first method (1) asks participants to place a marker at 3 locations that they would prefer to wait while at the train station. The participant is then able to wander the design option in order to choose three preferred locations. The second method (2) queries which qualities of a location are most important when choosing where to wait.

In applying these two methods, VREVAL requires two corresponding tasks: the Placing Task (T1), and a Default Task (T2). In T1 (Figure 6) participants are placed in the waiting area of a single design option and asked to place a marker at three locations that they would most like to wait for their train using the form “Waiting_Placement_Control”. T1 requires the researcher to select the required environment settings, user settings, along with a starting Marker (“Waiting_Control”) and Form (“Waiting Placement Intro”).

T2 (Figure 7) also places participants in the waiting area of the respective design before asking them to answer a multiple-choice question by selecting one or more from a list of waiting area qualities. In selecting content for T2, the same marker “Waiting_Control” is chosen, although linked instead with the qualities questionnaire form “Waiting_Placement_FollowUp”.

Finally, four evaluation groups were created (Control, Option A, Option B, and Option C) based on the different Playlists available, and participants were sorted using the question: “Is this your first year of university?”. In this way, the research team distributed the youngest and least academically experienced participants evenly throughout each evaluation group. As this is a between-group study, multiple Tasks, Scenarios, and Playlists are required in order to provide four study variants for Control and Options A, B, and C. Although much of the study Markers and Forms are identical in each variant, different environment bundles are required.
3.1 Study Sequence

A full study sequence (Figure 8) was created by the research team in order to regulate participant experience and was conducted by a student assistant. The waiting preference study was a part of a larger multi-section study conducted from November 24, 2021 and January 12, 2022 (Bailey et al 2022). The first phase [A] involved an introduction to the user study and the participant providing their informed consent. The second phase [B] had the participant wear the HMD and perform both a VREVAL tutorial of actions and the Playlist of VREVAL Scenarios for the full user study (Figure 8). Afterwards, the final phase [C] involved a quick debrief before the participant exited. Finally, the student attendant sanitized the equipment and switched out the HMD for the next participant. The full study sequence took approximately 45 – 60 minutes per participant, while the waiting preference section took 5-10 minutes on average.

In total, 62 participants (47 feminine / weiblich, 14 masculine / männerlich, 1 non-binary / divers) were involved in the study, with sorted between-groups (Control = 16, Option A = 15, Option B = 16, Option C
Most participants were bachelor or masters students at the Faculty of Architecture and Urbanism at Bauhaus-Universität Weimar.

4 RESULTS

Results from all participants were downloaded from the web platform at the end of the study period (December 2021 – January 2022). Statistical software was used for response analysis, and locations of preference were visualized in Autodesk Revit using the VREVAL Dynamo package.

4.1 Placing Task

Participant responses for preferred waiting locations were visualized in Autodesk Revit in order to show points of clustering, as marked in Figure 9.

Figure 9: Placement results for T1 in all Evaluation Groups.

Clusters were counted as 6 or more markers placed within a 3 meter radius. Two cluster locations were found in Control, one at a covered bench placed along Platform 1 and one at an uncovered bench by the bicycle racks along Platform 1. Option A saw three cluster locations: one location at a bench along Platform
Participant placements are also visualized based on their sequence (Figure 9) with green totems representing first choices, gold totems as second choices, and magenta totems as third choices. Although there were slightly elevated percentages of second and third choices outside of the station building area (marked with a red dashed line in Figure 9), distribution of sequenced locations shows little actionable data for determining first preferences in any of the design options. However, future analysis of pathways taken between sequenced placements could add in additional understanding of wayfinding behavior while looking for waiting locations.

Finally, demarcated areas (full design area, unprogrammed exterior area, station services area, interior waiting area) were used to understand the placing behavior of participants within the train station. Participant responses broadly preferred the unprogrammed exterior areas (areas without prior function, i.e. bicycle storage, parking, etc.). The distribution of participants throughout this exterior area was dependent on architectural form, with the open planning of Option C providing more even distribution than the closed court form of Option A. Control and Option had the highest proportion of participants choose locations in the unprogrammed exterior area, while all options retained the vast majority of participants within the full design area.

In each design option, only 1 participant chose to wait within the interior waiting area, showing that participants mostly preferred exterior waiting areas with the most direct visual relation to Platform 1. However, no formal language was used in describing weather conditions or temperature, so future research must engage with further environmental conditions to understand waiting preferences under various circumstances.

### 4.2 Qualities Questionnaire

In response to the follow-up question of T2 (“Which qualities do you find most important for a waiting area in a train station?”), participant responses in total show a distinct prioritization of “Visibility” (81%) and “Safety” (71%). As seen in Table 1, these two broadly important qualities were met by a more uneven set of responses to the remaining qualities.

<table>
<thead>
<tr>
<th>Multiple Choice Answers</th>
<th>Control</th>
<th>Option A</th>
<th>Option B</th>
<th>Option C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>The area must be an interesting space (Aesthetics)</td>
<td>4 (27%)</td>
<td>3 (19%)</td>
<td>9 (60%)</td>
<td>7 (44%)</td>
<td>23 (37%)</td>
</tr>
<tr>
<td>The area must have a visual connection to platforms and services (Visibility)</td>
<td>15 (100%)</td>
<td>14 (88%)</td>
<td>11 (73%)</td>
<td>10 (63%)</td>
<td>50 (81%)</td>
</tr>
<tr>
<td>The area must have a proximity to services (Services)</td>
<td>8 (53%)</td>
<td>7 (44%)</td>
<td>3 (20%)</td>
<td>3 (19%)</td>
<td>21 (34%)</td>
</tr>
<tr>
<td>The area must have an enjoyable view (Viewpoint)</td>
<td>10 (67%)</td>
<td>7 (44%)</td>
<td>6 (40%)</td>
<td>7 (44%)</td>
<td>30 (48%)</td>
</tr>
<tr>
<td>The area must feel very safe (Safety)</td>
<td>9 (60%)</td>
<td>13 (81%)</td>
<td>12 (80%)</td>
<td>10 (63%)</td>
<td>44 (71%)</td>
</tr>
<tr>
<td>The area must have a high amount of seating (Availability)</td>
<td>7 (47%)</td>
<td>6 (38%)</td>
<td>4 (27%)</td>
<td>8 (50%)</td>
<td>25 (40%)</td>
</tr>
<tr>
<td>The location must be restful and calm (Activity)</td>
<td>7 (47%)</td>
<td>7 (44%)</td>
<td>6 (40%)</td>
<td>10 (63%)</td>
<td>30 (48%)</td>
</tr>
<tr>
<td>Other reasons…</td>
<td>0</td>
<td>1 (6%)</td>
<td>1 (7%)</td>
<td>3 (19%)</td>
<td>5 (8%)</td>
</tr>
</tbody>
</table>

While overall qualities of influence were registered in all design options, some responses showed dependence on the between-group. Interestingly, the quality “Activity” received majority responses (63%)
in Option C, and “Viewpoint” received a majority of responses (67%) in Control. Option C might have highlighted “Activity” by the distribution of planter elements, thus increasing participant response through a demonstration of the quality. In contrast, the choice of “Viewpoint” in Control – an option with limited viewpoints – might have been in reaction to the absence of the quality.

“Aesthetics” was found to be more important to participants in Options B (60%) and received a majority of responses, while receiving less than a majority in Control (27%) and Options A (19%) and C (44%). It is notable that Options B and C are more stylized, thus possible that “Aesthetics” was valued higher when more noticeably present, but otherwise not a strong indicator of waiting preference. The value of “Services” was rated quite average in Control (53%) and Option A (44%), and lower in Options B (20%) and C (19%).

The list of qualities provided seemed adequate, as very low responses were given to “Other Reasons…”. However, it is clear that the framing of qualities might have an interpretive effect on participants. Under the condition of selecting “Other Reasons…”, the study attendant asked the participant to explain their reasons and marked these down in the study log. While a majority of these responses were conceptually similar to already present qualities on the list, “green space” appeared twice in these responses as a reason for choosing a location to wait.

5 DISCUSSION

In this paper we have presented the design and execution of a waiting preference user study using the updated VREVAL framework, showing how to integrate VREVAL user studies into the architectural design process, and how to utilize VREVAL user studies in making design decisions. The development of the VREVAL web platform provides centralized researcher access to modular study design, administration and review, which limits the requirement for researchers to maintain specific software and programming knowledge. VREVAL also simplifies the processes of study implementation via the desktop application in either HMD or Monitor Mode.

In this study, four train station design options were compared in terms of waiting preference, and while there is no simple “best option” in the study results, the participant chosen locations for waiting show behavioral differences based on architectural form and station planning. These results provide the general preference for station building designs that distribute waiting areas along Platform 1 and combine direct visual connections with material boundaries. Further, responses to the follow-up questionnaire support these assumptions by highlighting the shared waiting preference qualities of “Visibility” and “Safety” of most participants. While a large portion of recent IVE-based architectural studies have concentrated on wayfinding behavior (Ewart and Johnson 2021, Arias et al 2021, Zhang et al 2021), this study has also shown the possibility of appraising locational preferences via placing tasks and questionnaires situated in IVEs.

Future analysis of waiting preferences from this study and others should combine participant responses from VREVAL with locational analysis of visibility and centrality. Combining preferred locations from the IVE with Isovist analysis, centrality analysis and other available computational tools will allow for a preliminary modelling of waiting qualities to be used as a predictive tool.

5.1 Outlook

Continued research must focus on performing more studies for a better developed understanding of behavior and preference in a variety of project types and spatial organizations. Additionally, several technical topics within IVE study design remain unclear in term of their influence on participant responses:

- Level of Detail (LOD) in IVEs and methods of Material Representation must be understood in the ways that they effect participant immersion and distance perception.
- Environmental Conditions (Weather, Time of Day, etc.) must be included in studies that assess participant preferences, especially in exterior spaces. Previous research has already show the utility
of IVE-based studies on lighting conditions, and other environmental aspects that are difficult to control in real-world settings (Heydarian et al 2015, Krösl et al 2018).

- Static or dynamic use of entourage must be understood in how it affects participant wayfinding and preference behavior. Current research shows that animated crowds have an effect on participant behavior (Yassin et al 2021), although more research must be done on how and when to mitigate these effects.

Further, there are topics of research which must address the IVE and narrative methodologies used. The most studied of these topics is the difference between IVE and real world participant responses (Interrante et al 2006, Clemenson et al 2020). For the most part, there is now general acceptance of parity between IVE and real world experiments in Wayfinding and Questionnaires (Ewart and Johnson 2021, Wagener et al 2020), but other tasks (Placing, Pointing, Distance Perception, etc.) must be shown to be reliable within IVE-based studies. Also, the narrative devices used in IVE-based studies is a future field of research that should engage what level of background information is required for participant understanding, what narrative basis is best for user study requirements, and generally what specific language is best used when describing virtual actions and spaces.

Finally, a set of best practices for VREVAL and other IVE frameworks must be developed in tandem with further studies in order to maintain the highest level of impartiality and reproducibility possible. However, much of the best practices remains on the discretion and knowledge of the researcher, as a highly flexible framework for IVE-based user studies cannot be seen as the limiter of biases.

ACKNOWLEDGMENTS

This study is part of the project OpenVREVAL, in cooperation with Deutsche Bahn Station & Service AG and funded by the Thüringer Ministerium für Wirtschaft Wissenschaft und Digitale Gesellschaft (TMWWDG). Special thanks are given to Paul Leon Pollack for study assistance, and to the students from Bauhaus-Universität Weimar for their creative input and investigative spirit.

REFERENCES


**AUTHOR BIOGRAPHIES**

**SVEN SCHNEIDER** is Interim Professor and Chair at the Professur Informatik in der Architektur at Bauhaus-Universität Weimar: sven.schneider@uni-weimar.de.

**OLAF KAMMLER** is a Research and Teaching Assistant at the Professur Informatik in der Architektur at Bauhaus-Universität Weimar: olaf.kammler@uni-weimar.de.

**GRAYSON BAILEY** is a Research Assistant at the Professur Informatik in der Architektur at Bauhaus-Universität Weimar: grayson.daniel.bailey@uni-weimar.de.

**RENÉ WEISER** is a software developer at the Professur Informatik in der Architektur at Bauhaus-Universität Weimar: rene.weiser@uni-weimar.de.

**EKATERINA FUCHKINA** is a Research and Teaching Assistant at the Professur Informatik in der Architektur at Bauhaus-Universität Weimar: ekaterina.fuchkina@uni-weimar.de.