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User-Centred Performances in Train Station Design

An IVE-based User Study of Four Design Options

GRAYSON BAILEY, OLAF KAMMLER, SVEN SCHNEIDER, EKATERINA FUCHKINA, &

RENE WEISER

BAUHAUS-UNIVERSITÄT WEIMAR, GERMANY

ABSTRACT

The existing train station for the town of B (anonymized) in Germany is planned to be replaced with a new building. Three architectural design options have been developed in a student design studio, which differ in spatial configuration and architectural expression. With an Immersive Virtual Environment (IVE) based user study, the advantages and disadvantages of these designs will be identified with respect to user behaviour and experience. In a between-subject study participants (N=62) are divided into four groups with each evaluating either one of the three design options or the existing station. Participants are asked to evaluate spaces using semantic differentials, navigate the virtual environment, and provide responses to prompts via IVE questionnaires. The study is composed of multiple sections which survey Ease of Orientation, Route Choice, Spatial Experience and Distance Perception and Waiting Area Experience. The initial results of the study are presented here to show differences of perception among schematic design options and demonstrate the potential of such studies to provide instrumental feedback during the architectural design process. The paper shows how IVE-based user studies can be used to study behavioural aspects of train station design and provide insights on how to design and conduct IVE-based user studies with repeatable methods using the VREVAL framework. The results of the study illustrate the potentials of implementing such studies in schematic design processes and provide a basis for further analysis of how configurational features of architectural space, such as visibility and accessibility, relate to user behaviour and experience.

KEYWORDS

Pre-Occupancy Evaluation, Virtual Reality, User-Centred Design, Building Information Modelling, Architectural Education

1 INTRODUCTION

User studies allow for qualitative and quantitative analysis of architectural spaces through investigating aspects of architectural experience which are not easily computable. User studies of architectural designs are used to study spatial cognition (Dalton et al. 2010), create frameworks for categorizing architectural perceptions (Kim and Cho, 2017), test the validity of designer's assumptions in architectural works (Kuliga et al. 2019), and inform regulatory and maintenance practices in the built environment (Preiser, 2001).

The main form of User-Centred Evaluations has historically been the Post-Occupancy Evaluation (POE), which takes place only after construction. Deuble & De Dear (2014) reviewed the state of the POE processes of the UK and divided the major uses and misuses of POEs. The major uses were designer feedback, improved commissioning process, information for regulatory processes, and targeting of refurbishment. Major misuses were lack of context, lack of feedback, and lack of instrumental data. In addressing the lack of feedback and lack of instrumental data, while retaining the advantages of POEs, an Immersive Virtual Environment (IVE) allows for a User-Centred Evaluation to take place during the design process, also known as Pre-Occupancy Evaluation (PrOE).

The use of IVEs in evaluating architectural designs has been increasing for the last two decades, especially with the reliability and interconnection of data possible with recent Virtual Reality (VR) technologies and development of software frameworks for utilizing VR technology in architectural research. IVE-based user studies have largely focused on the user experience of specific interior architectures which would otherwise require expensive design mock-ups (Dunston et al. 2011; Crescenzio et al. 2021), the comparison User Experience ratings with computational analyses of visibility and connectivity in urban and architectural spaces (Fisher-Gewirtzman et al. 2019), or the tracking of movement behaviour and orientation during wayfinding processes (Natapov et al. 2022; Irshad et al. 2021). With the development of more affordable VR technologies and the design of new VE/VR frameworks for architectural research (Schneider et al. 2017; Moloney et al. 2019; Wölfel et al. 2021), the accessibility of architectural user studies is significantly increasing.

In this paper we will present an IVE-based user study which was used to test and compare different design options for a train station in a small German city. The user study examines wayfinding behaviour and route choice, location preference for waiting within the train station design and the rating of spatial experience and distance perception throughout different key locations. The study represents a schematic comparison phase of the design process, with multiple design options which must be compared for further design development. The study involved 62 participants reviewing different user centred performances of train station designs within an IVE. In this paper a summary of methods and initial results is presented. Finally, conclusions about the efficacy and direction of development for such studies are drawn.

2 CASE & STUDY SETUP

The real-world case for the following study is a German train station building in the anonymized city of B. As seen in Figure 1, the train station provides through-traffic and bisects the city into northern and southern sections. A major pedestrian connection between these sections is an underpass located directly east of the train station, which contains a building with a fast-food restaurant and kiosk, and a set of stairs directly from the underpass to Platforms 2 and 3 of the train station. On the southern side of the rail lines there are areas for ancillary bicycle parking, taxis, and stops for public bus lines. The current train station building is intended for replacement due to several reasons: 1) the building is run-down, 2) the programming is out of date, and 3) the building is not adequately accessible to the pedestrian underpass (Underpass 1), making it an unattractive location for commercial development (see Figure 1).

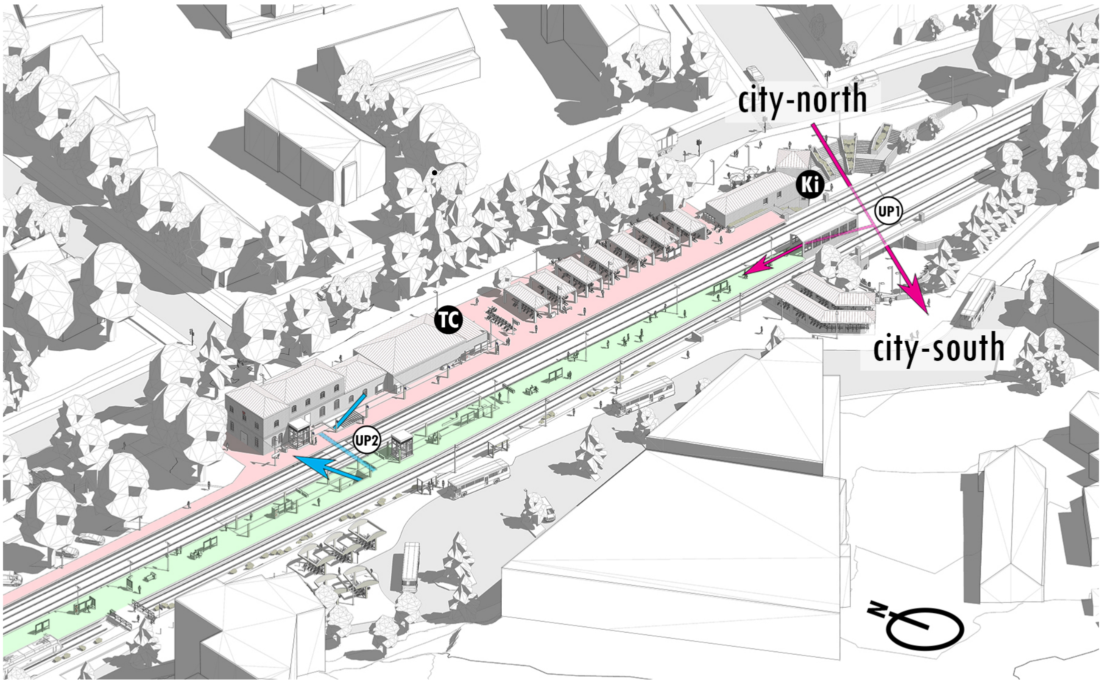

Figure 1: The Train Station and context environment within the study. The Train Station Building (TSB) area is highlighted in red, Platforms 2 and 3 are highlighted in green. Two paths are marked: Underpass 1 (UP1) is a sub-level walkway from city-north to city-south with a staircase to Platforms 2 and 3, and Underpass 2 (UP2) is a staircase and elevator route from the TSB to Platforms 2 and 3. Within the current construction the Travel Centre (TC) and Kiosk (Ki) are marked with dots.

Three alternative design options for a new train station building (Options A, B, C) were developed in a master student design studio (winter semester 2020/21), and the current train station building is used as a control option for comparison to the new designs. The control is a single building on the western side of the site with seven covered racks for bicycle parking between the station building and Underpass 1. Option A divides the new program into three buildings creating an intimate waiting area enclosed on three sides. Option B consists of a single elongated building with covered waiting cabins along the adjacent track. The entrance to Option B is also closest to the entry plaza and provides the most immediate direct visual access to the train platforms. Option C again separates the program into three buildings, however more evenly distributed than option A, creating a more open waiting area with visual connections to the surrounding urban context and a planter-based seating. In all three design options the waiting area along the track is covered by a roof. Thereby the shape of the roof differs from simple flat in option A to wave-like in option B and low with many skylights in option C (see Fig 2).

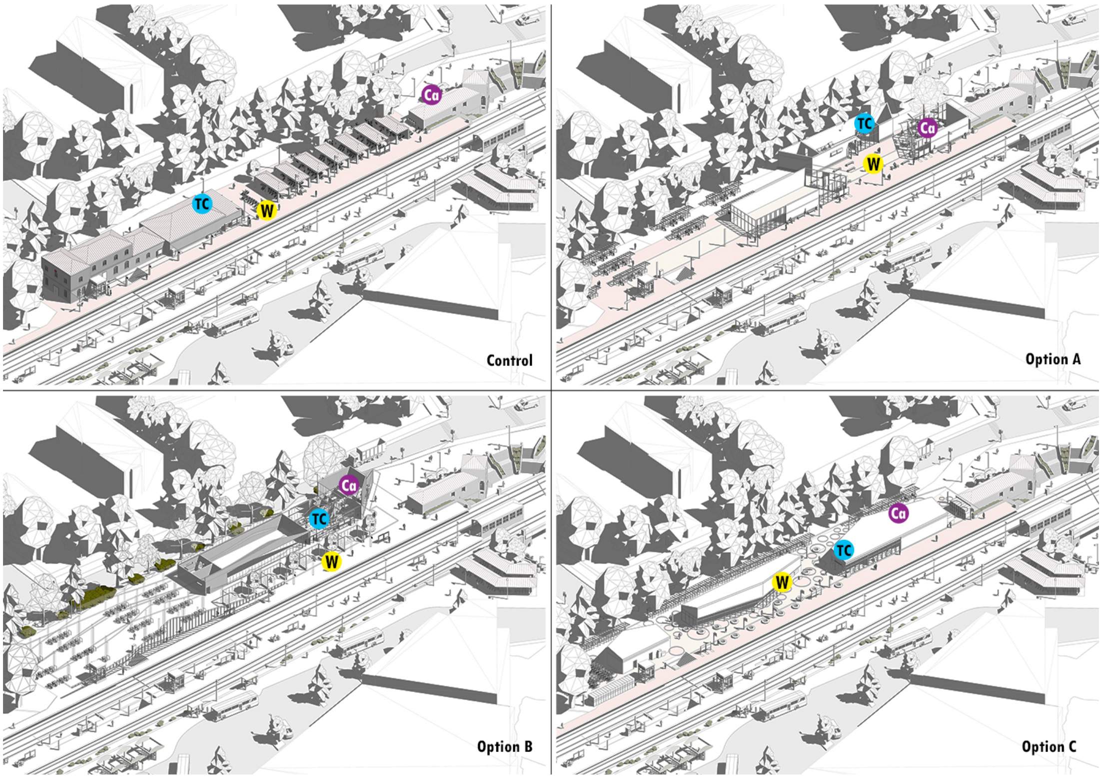

Figure 2: The four design options for a train station which were used in the study. Control is the current construction and acts as the control design. Blue 'TC' symbols represent the location of the Travel Centre, yellow 'w' symbols represent designated Waiting Areas, and 'Ca' symbols represent the café areas.

The focus of this study is to compare the design options with respect to different user-centred aspects, which are: ease of orientation, route choice, spatial experience, waiting experience, and distance perception. Beyond this focus on architectural effects on behaviour and experience, two subsequent aims of the project concern the design and efficacy of such IVE-based evaluations. First is to evaluate the application of such studies during the choice phase in the design process, and the second is to examine points of efficacy in the study design in order to create a set of best practices and understand where IVE-based scenarios and analysis must be further developed.

2.1 Participants and Study Sequence

The study involved 62 participants (47 female, 14 male, 1 diverse) who were unfamiliar with the design options. Most of the participants were undergraduate architecture students in their late teens to mid-twenties, and almost all participants had little experience with navigating IVEs or using VR technologies. Students in their first year of university were evenly distributed among the four groups, as they represented a population with little previous knowledge of Architecture or the design of navigable spaces. Personal demographics of age, gender, and levels of experience were attained anonymously during the personal questionnaire follow-up to the study, although a detailed analysis of participant demographics will be left out from this paper.

The study sequence was 45-50 minutes on average, including an introduction which explained goals and basic VR interaction before the performance of the study. An attendant guided each participant through the study sequence. The study sequence began with an introduction to the study and presentation of informed consent material, followed by a 5–10-minute User Tutorial conducted to introduce participants to the VR controls and interaction. Once the User Tutorial was completed, and the formal user study began.

The study comprised four sections: (1) Route Choice, (2) Waiting Preference, (3) Spatial Experience, (4) Distance Perception. After these study sections followed a personal questionnaire which could be completed within the IVE or in a desktop mode. Primary locations for participant insertion and scenario performance were indexed and abbreviated as CS for Carside on the street corner, EP for Entry Plaza, SI for Station Interior, NC for Norther Carpark, SC for Southern Carpark, PL for Platforms 2+3, and SP for South Plaza. Between-Group specific locations were also chosen based on the locations of Travel Centres and primary Waiting Areas for each of the four groups. Study sections and the necessary models used in the IVEs were prepared with Autodesk Revit.

As the participants completed each section of the study, the study attendant took notes of questions asked by the participant. In the case of cyber sickness, either a short break was taken, or the study was left incomplete. Due to COVID-19 restrictions, two HMD + Controller sets were interchanged after each participant, with the previously used set being wiped down with disinfectant and cleansed with a UV-Light Sanitizer.

3 ROUTE CHOICE

The first section of the study examines route choice behaviour via wayfinding tasks. Wayfinding is an essential indicator of building/architectural usability (Arthur & Passini, 1992), which is often overlooked in the design phases (Kuliga et al. 2019). In IVE-based studies wayfinding is the most prevalent task performed, as they allow to examine the exact pathways and orientation of participants quantitatively as well as providing questionnaires for qualitative feedback. Many studies have examined occupant wayfinding during emergency evacuation (Irshad et a. 2021; Gath-Morad et al. 2021), as well as the role of architectural forms on the wayfinding process (Zhang et al. 2021; Natapov et al. 2022). Wayfinding tasks in IVEs have been mostly validated through experiments between real-space, non-immersive VEs, and IVEs (Feng, 2022; Arias et a. 2021) although there remains a lack of comprehensive research. Wayfinding and route choice requires more repeatable studies which examine the effects of architectural form on wayfinding behaviour, and this study focuses on the specific situation of choice between two paths in a real-world situation.

In this study section, the primary goal (*RC-G1*) is to test which design most efficiently draws participants into the new station area and thereby increases the economic potential for the station. The subsequent goals are to understand which specific qualities are self-reported to determine choice between two pathways (*RC-G2*), to discover which design is easiest to navigate (*RC-G3*), and to discover which design option is considered the most welcoming to enter (*RC-G4*).

3.1 Method

In order to make a route choice, first the participants must be made familiar with the station. Therefore, two tasks for exploring the two possible routes are given. The first asks to find a checkpoint on Platform 2 through the train station via an intermediate stop (the Travel Centre); the second asks to start at Platform 2 use the alternative path to a pick-up location via an intermediary stop (the Kiosk). In the third task the participants are finally asked to find Platform 2 once more with whichever pathway they prefer.

The first task (*RC-T1.1*) places the participant at checkpoint SC and describes a situation in which they must find the Travel Centre to receive a pre-ordered train ticket. Upon arriving at the Travel Centre, a new prompt appears, and the participant is asked to rate (1-5) how easy the location was to find (Table 1). Afterwards, the second part of the task (*RC-T1.2*) is explained, asking the participant to find the next checkpoint on Platform 2.

The second task (*RC-T2.1*) places the participant on Platform 2 in front of directional signage and asks to find the Kiosk at the end of the Platform in the Lower Plaza. Once they arrive at the Kiosk they are once again asked to rate the ease of finding the Kiosk. The second part of the task (*RC-T2.2*) is then explained, telling the participant that they should find a red car at the intersection near the checkpoint SC.

Finally, the third task (*RC-T3*) places the participant at checkpoint SC once more and explains that they should make their way to Platform 2 via whichever pathway they would like. Once they have entered an area that explicitly declares their intent of pathway, a question prompt appears, asking them to select one or more qualities which were important in making their route choice from a list of prepared answers (Distance, Ease, Visibility, Safety, Welcomeness, Aesthetics, Activity, Other), as seen in Table 2. If the participant chooses “Other Reasons”, the study attendant asks them to verbally explain their intended reason and takes note in the study log.

3.2 Results

In Figure 3 the participant pathways for each phase of the Route Choice study section are color-coded and the rate of route choice is marked. Resultant choice numbers are overlayed. In *RC-T1.1*, among all options 84% of participants walked directly through the station design area, whereas 16% investigated Underpass 1 before returning to the actual station area. Two options (Control, Option B) represented 90% of these cases, which might indicate a lower level of “welcomeness” of these two options (*RC-G4*). The responses to question *RC-T1.1* varied between "neutral" (3) and "easy" (2). Two variants (Control, Option A) were rated slightly more positive ($M_{Control}$ = 2.56 and M_A = 2.57), while Option B and Option C were rated as neutral (M_B = 2.94 and M_C = 3.0).

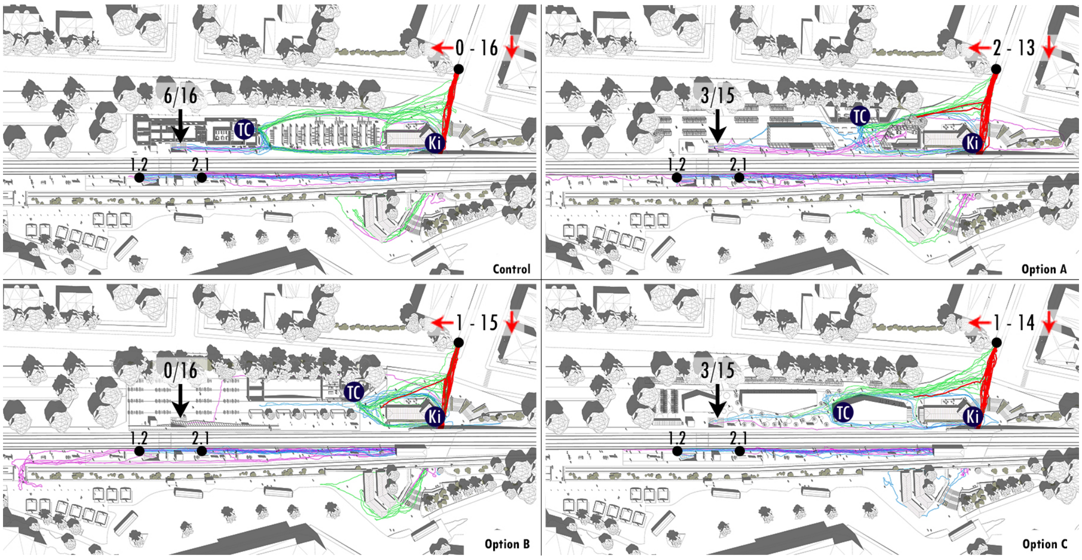

Figure 3: Route Choice section results. Checkpoints (starting points, Travel Centre, Kiosk, ending points) in each design option are visualized by location abbreviations. Participant paths are visualized for each design option with different colours for each task-part: RC-1.1 = Orange, RC-1.2 = Magenta, RC-2.1 = Green, RC-2.2 = Blue, RC-3 = Red.

The wayfinding behaviour during *RC-T1.2* highlighted the challenge of correctly introducing both pathways to participants. Only 20% of total participants utilized the intended route through the train station. This can be interpreted as the bias of previously provided information, with most participants believing that Underpass 1, which they had seen in *RC-T1.1*, was the main route to Platform 2. Additionally, Control had the highest rate of intended path usage (37.5%), which is most likely because of the close connection between Travel Centre and Underpass 2.

RC-2.1 participant paths also show a high amount of exploration before finding the Kiosk. Although there were direct instructions given, signage placed in the IVE, and a higher-than-expected amount of participants were already passing by the Kiosk during *RC-T1.2*, a total 24% of participants explored in the opposite direction of the kiosk. Option A had the highest percentage of 'wrong-turners' (33%) and Option C the lowest (12.5%). This is most probably an indicator of low instruction comprehension or readership. Responses to the *RC-T2.1* question found that participants generally found the Kiosk equally easy to find as the Travel Centre (M_{All} = 2.55), whereby Option A was rated most "difficult" (M_A = 3.27) and Option B was found to be the most "easy" (M_B = 1.94).

In order to compare the different wayfinding performances, we calculated the length of the participant paths in contrast to the shortest paths between task locations. As illustrated in Figure 4, the percentage of deviation from the shortest paths indicates that Options A and C were the easiest to navigate in *RC-T1.1*, and finding the Travel Centre was the most difficult in Option B.

All design options approximately doubled the shortest path for *RC-T1.2*, which relates to the low number of participants who took the intended path to Platform 2. Otherwise, the paths to the Travel Centre in *RC-T1.1* differed most from shortest paths (between 133% and 215%). When focusing on RC-T1.1 and 2.1 alone, we can state that Option B had the highest level of deviation from shortest paths (193%) and Option C had the lowest (126%).

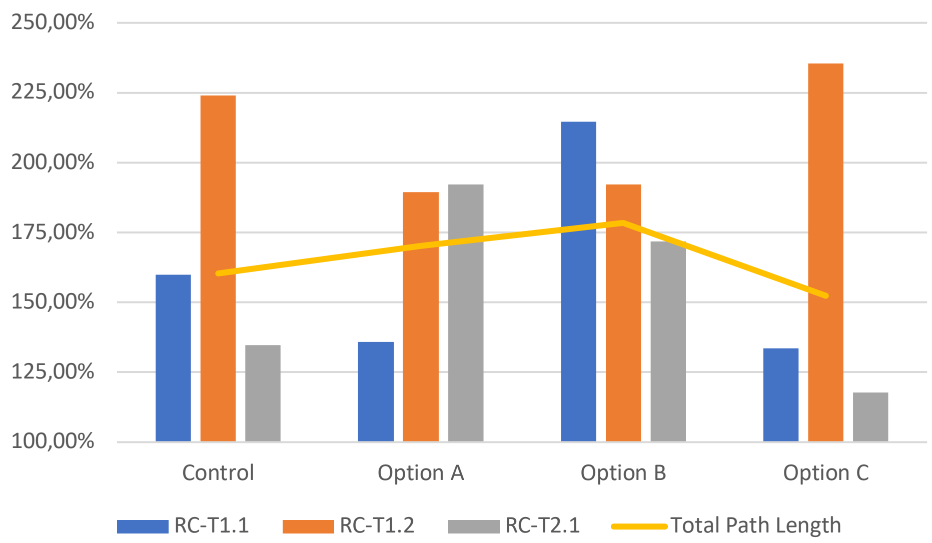

Figure 4: Deviation of the participant paths from the calculated shortest distance (100%) for each task and design option.

RC-T3 showed a distinct preference for Underpass 1: 6% of participants chose Underpass 2, the lowest rate (0%) marked for Control and the highest rate (13%) for Option A. Each design option performed marginally better than Control, which might also contribute to an interpretation of Option A as the slightly more welcoming design in response to *RC-G4*. In the follow-up questionnaire in *RC-T3* (see Table 2), “Visibility”, “Distance”, and “Ease” were the most chosen qualities for making route choices (*RC-G2)*. Interestingly distance was perceived as shorter, the actual distance of both pathways were the same. This indicates that the more visible paths might be also perceived as shorter. However, drawing any conclusions in respect to *RC-G1* would be questionable, as the methods for introducing both pathways was severely undercut by the unexpected behaviour of participants. The visual prominence of Underpass 1 in the first experience of the IVE seems to strongly attract participants, especially when the alternative underpass in the train station is not equally visually prominent in any of the design options. However, the choice between paths might have resulted similarly because the path through the underpass is more visible and requires less direction changes.

Table 1: RC-T3 Multiple-choice quality selections of all participants.

Quality Selection	*Count*	*%*
I'm not sure, I was just wandering…	0	0%
I expected this path to be the shortest (Distance)	51	32%
I expected this path to be the simplest (Ease)	38	24%
I could see the path to Platform 2 this way (Visibility)	38	24%
I expected this path to be the safest way (Safety)	6	4%
I expected this path to be the most inviting (Welcomeness)	10	6%
I expected this path to be the most beautiful (Aesthetics)	4	3%
I expected this path to be the liveliest (Activity)	7	4%
Other reasons...	3	2%

4 WAITING PREFERENCE

The waiting preference (WP) study section is about location preferences for waiting within the train station designs. User experiences of train stations follows a wave-like fade from enjoyment to stress, and the waiting duration before rail travel or during exchanges between trains is often the most stressful or least enjoyment portion of the journey (van Hagen, 2011; van Hagen and Bron, 2014). While factors of enjoyment are largely outside of architectural purview, seating preference has proven to have direct effects on the experience or performance of occupants in other situations (Zomodorian et al. 2012; Keskin et al. 2015). Correlating seating preference with spatial qualities is crucial for predicting choice behaviour in train station design. Seating choice experiments have been conducted in relation to space syntax in commercial planning (Keszei et al. 2019). Similar experiments in transit architecture will possibly shed light on how to more efficiently plan for higher occupancy of waiting area seating, as it has in educational planning (Gou et al. 2018; Tunahan et al, 2021), or how various demographics and user profiles affect the choice of seating (Clark and Walker, 2020).

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In this study section, seating choice is examined in alternative train station designs, . The primary goal of this section (*WP-G1*) is to determine where participants want to sit in which design option and in how far these choice correlate with the primary waiting areas designated by the designers. Second, we want to identify the qualities which were most influential for the participants choice (*WP-G2*).

4.1 Method

Two tasks are performed to assess the preference of seating location and the qualities which are most important in choosing a place to wait within the train station. In the first task (*WC-T1*) the participants are asked to find three locations where they would prefer to wait within the train station and place a marker at those locations in the IVE. The participant is first placed in the area designated for waiting (as seen in Figure 2) and then is allowed to move around the IVE without a time constraint. Once the participant has placed three markers, the task is completed, and the participant is returned to the initial waiting area checkpoint. There, a multiple-answer questionnaire (*WC-T2*) is displayed, asking “Which qualities do you find most important for a waiting area in a train station?”. The participant is able choose from a list of pre-selected statements, as seen in Table 3, which correspond to different qualities such as Aesthetics, Visibility, Services, Viewpoint, Safety, Availability, Activity. If the participant selects “Other Reasons”, the study attendant asks them to verbally explain their intended reasons and takes note in the study log.

4.2 Results

For the analysis of *WP-T1*, chosen waiting locations are mapped to architectural models in Figure 4. Generally, there was a clustering of seating preference in all options around provided benches and areas adjacent to the platforms. There were two identified clusters of preferred locations in Control: one within the exterior designated waiting area (located at a bench in the covered area along Platform 1), and one outside of the waiting area (located at a bench nearby the bicycle storage). In Option A, a major cluster of responses is located outside the designated wating areas along a wall facing Platform 1. This location has a physical proximity to the platforms, high visibility of platform activity, and a solid material behind the waiting area, which are all features not provided in the trapezoidal exterior waiting area. Two smaller clusters are located along the Café building and another small cluster is located at the front corner of the trapezoidal waiting area.

Clusters in Option B take place in each of the designated waiting cabins along Platform 1, as well as a small cluster in the Café area. Loose placements in Option C are spread more widely (along Platform 2, Underpass 1, and in the South Plaza) than in other options, though most locations tend to cluster close to the tracks. Interestingly, the interior waiting areas received only one participant response in each design. However, choice in this regard would be heavily affected by the language used in describing weather and temperature conditions; in this respect, no specifications were made in our study.

In order to quantitatively compare the design options, the number of preferred locations inside the primary interior and exterior designated waiting areas was calculated (see red outlines in Figure 4). The containment rates of all options (Control = 22.0%; A = 44.4%; B = 62.5%; C = 48.9%) show that each new design outperforms the control. In respect to *WP-G1*, Option B has the highest containment for all markers placed (62.5%). Participant waiting preferences also indicate that architectural composition had a discernible effect on the success of designated waiting locations. Generally, the seating aligned to Platform 1 (Options B and C) scored higher containment rates, although alignment to Platform 1 without a designed waiting area (Control) scored lower. Most of the locations placed outside of the designated waiting areas in Control and Option A were placed along Platform 1, showing a consistent participant location along the platform’s edge. The primary waiting space of option A, which was intended to provide high level of enclosure and intimacy, was least preferred among the three designs.

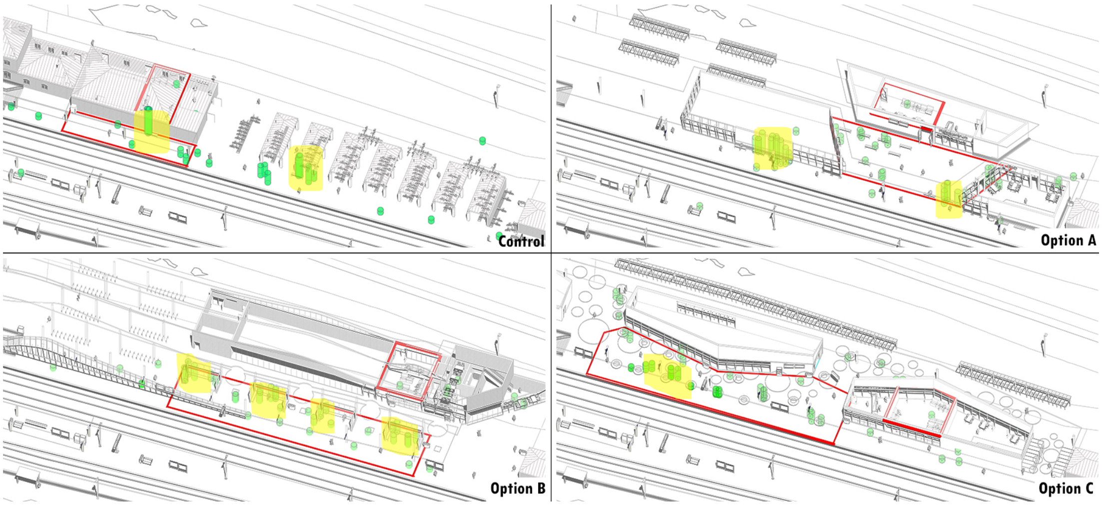


Figure 4: *WP-T1* marker placements for each design option. Red outlines denote the designated waiting areas for each option.

The responses to *WP-T2* were aggregated for all design options (see Table 3), as the results are not exclusive to design options. They address the selected qualities which were most important for choosing a waiting location in a train station (*WP-G2*). The most important qualities were “Visibility” and “Safety”, which each represented >70% of participant selections. “Viewpoint”, “Activity” and “Availability” were the second most important, each selected by > 40% of participants. Least often chosen were “Aesthetics” (37%) and “Services” (34%). In the category of “Other reasons…”, participants mentioned “proximity to greenery”, “conditioned for weather”, and “seated against a wall”.

Table 2: *WP-T2* Multiple-choice question and responses.

WP-T2 Question	*Multiple Choice Answers*		
Which qualities do you find the most important for a waiting area in a train station?	The area must be an interesting space (Aesthetics)	23	37%
	The area must have a visual connection to platforms and services (Visibility)	50	81%
	The area must have a proximity to services (Services)	21	34%
	The area must have an enjoyable view (Viewpoint)	30	48%
	The area must feel very safe (Safety)	44	71%
	The area must have a high amount of seating (Availability)	25	40%
	The location must be restful and calm (Activity)	30	48%
	Other reasons…	5	8%

5 SPATIAL EXPERIENCE

The Spatial Experience section of the study involves one task for the appraisal of spatial qualities at six locations in the IVE, and a separated task which asks participants to choose between four design alternatives at five of the same locations. Surveys of environmental perception can be divided into two main groups, with recent real-space and IVE studies alike focusing on the changes in user perception depending on alteration in architectural spaces (Kim and Cho, 2017; Crescenzio et al. 2021; Naz et al. 2017) or urban spaces (Radaczewska et al. 2019; Fisher Gewirtzman et al. 2019; Yuan et al. 2018). Spatial experience remains an ongoing topic in behavioural and perceptive psychology, both in the neuroscientific analysis of spatial experiences (Jelic et al. 2016) and the differences in perception which are caused depending on the type of presentational media (Toskovic et al. 2021).

As for the second task, design option choice is one of the most used methods for comparing alternative designs, although this usually takes place by using representational media such as rendered images, diagrams, plans and sections, which are not immersive. IVEs have been used in the design process in recent years as a method for presenting designs to the public (Loyola et al. 2019; Flacke et al. 2020) and for crowd-choice among multiple options (Vuong et al. 2013; Dijkstra et al. 2003; Van Leeuwen et al. 2018). Recent research has shown that IVE-based choices among multiple design options has a lower level of hypothetical bias than other presentational methods (Fang et al. 2020) and that anecdotal evidence shows participant happiness with choice experiments in IVEs (Samarashinge et al. 2021). Participant navigation of the space has also been found preferable to other forms of prescriptive presentational methods in IVEs (Rid et al. 2018). Looking to the future of VE methods for choice experiments, data-driven methods for organizing respondent data have also been in development (Gret-Regamey, 2014) as well as various methods for participatory design (Städler, 2021). The combination between spatial experience questionnaires and design choice option in this section will allow for the analysis of rated experience in relation to preference from select locations, which should also open further directions for developing the combination of these tasks in the future.

This study section has four primary goals, with the first (*SE-G1*) being to determine the differences of participant experience in the design options at several locations. The second (*SE-G2*) is to discover connections between the evaluation of the Entry Plaza and the decision use Underpass 2 during *RC-T3*. Potential connections between spatial experience and route choice would allow for the evaluation of "welcomeness". The third (*SE-G3*) is to determine the most preferred design option among the four alternatives in total as well as at each of the locations surveyed, and the final goal (*SE-G4*) is to discover connections between the preferred design at each location and the detailed ratings given at each of those locations.

5.1 Method

The Spatial Experience study section is separated into two tasks which are performed separately. In the first task (*SE-T1*) the participant is placed at five checkpoints within the IVE (see Figure 5) in the following order: 1. South Plaza (SP), 2. Station Interior (SI), 3. Northern Carpark (NC), 4. Platforms (PL), and 5. Entry Plaza (EP). At each of these locations the participant is asked to rate the surrounding space with a semantic differential containing 9 opposite word pairs, as seen in Table 5. The rating scale ranges from 1 to 5, giving the opportunity for neutral responses.

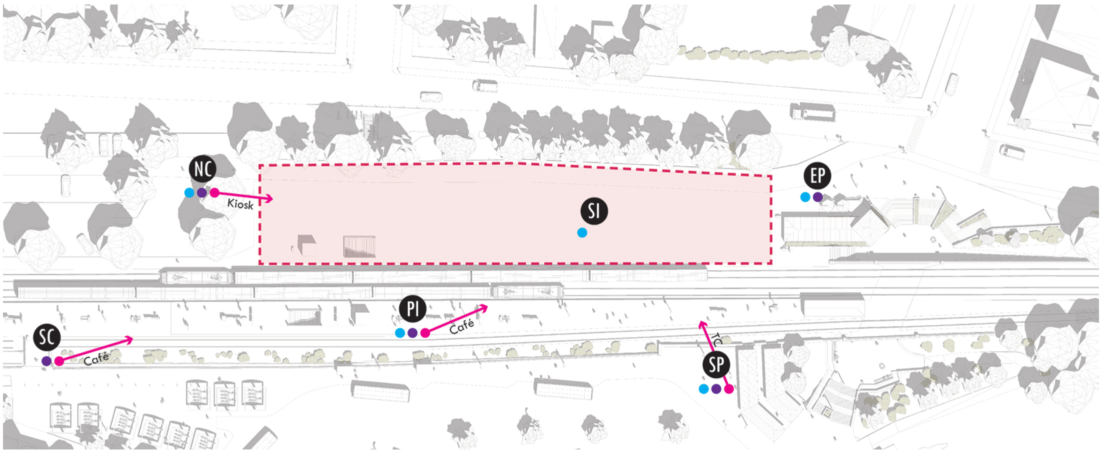


Figure 5: Map of Checkpoints and relevant locations in the Spatial Experience and Design Option Choice, and Distance Perception and Visibility study sections. Checkpoint locations are marked with black circles and checkpoint name abbreviations. At each checkpoint location, the study section tasks are marked whether they are assessed by placing a corresponding colour below the checkpoint: Blue = Spatial Experience, Purple = Design Option Choice, Magenta = Distance Perception. Distance Perception tasks show the referent location and direction as marked.

Table 3: *SE-T1* prompts and semantic differential ratings for participant spatial experience

This space looks…	Boring	○	○	○	○	○	Interesting
	Ugly	○	○	○	○	○	Beautiful
	Unbalanced	○	○	○	○	○	Balanced
I would imagine this space to be…	Dirty	○	○	○	○	○	Clean
	Loud	○	○	○	○	○	Quiet
	Unsafe	○	○	○	○	○	Safe
This space seems…	Chaotic	○	○	○	○	○	Ordered
	Narrow	○	○	○	○	○	Spacious
	Isolated	○	○	○	○	○	Connected

In the second task (*SE-T2*) the participant is placed at five checkpoints in reversed order: 1. Entry Plaza (EP), 2. Platforms (PL), 3. Northern Carpark (NC), 4. Southern Carpark (SC), 5. South Plaza (SP). At each location the participant is prompted with the question, "From this position, which of the design options is most preferable in your opinion?". The participant selects from a list of the design options, which switches between the models in the IVE to evaluate the differences among design options in order to make their choice.

5.2 Results

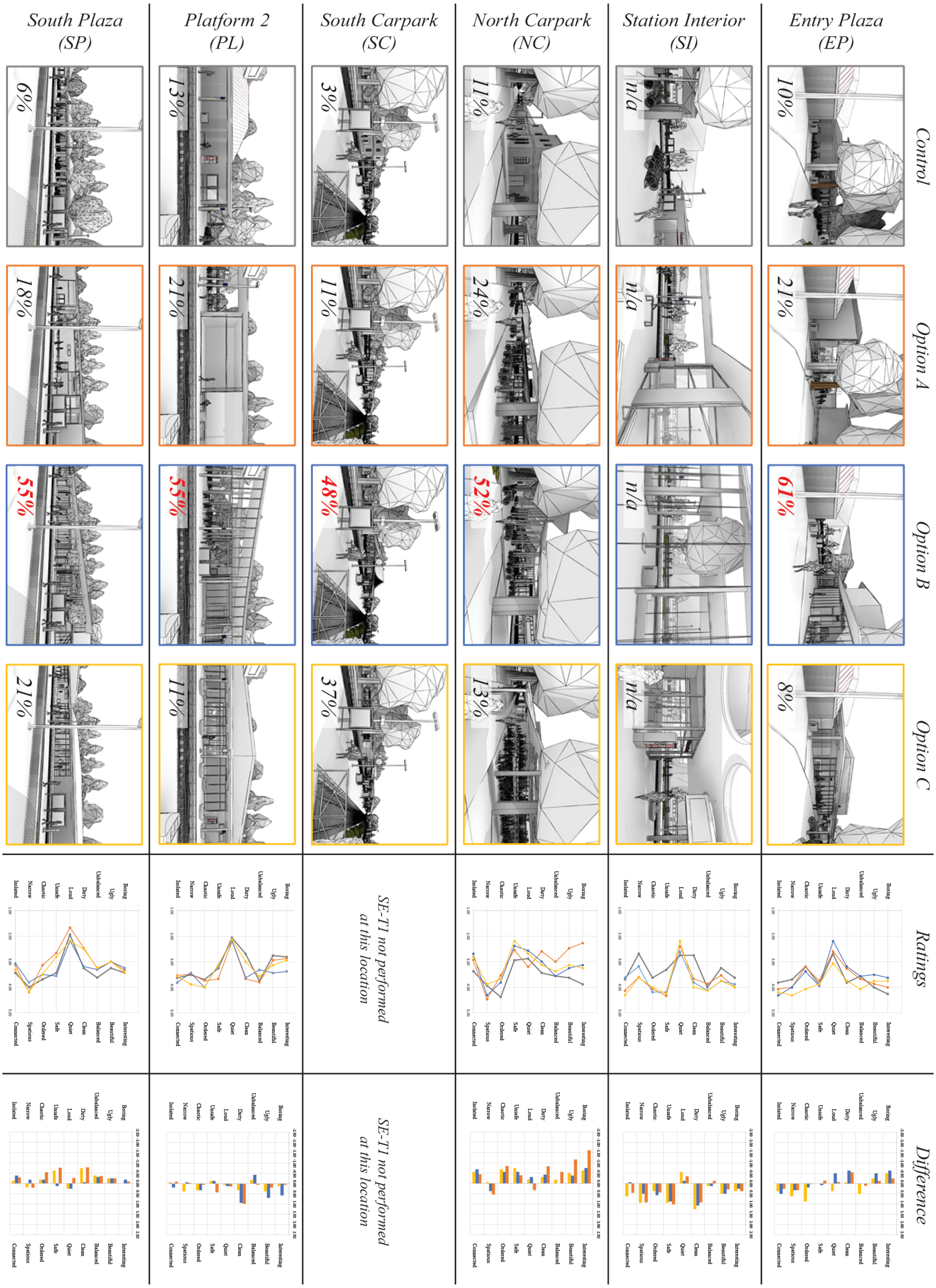
Results for SE-T1 can be found in Table 6, which shows the vantage points of each position with the semantic differential responses from participants and the deviations of the design options against Control responses. Participant responses were predictably highly dependent on checkpoint location, with two vantage points showing preference for the new design options (SI, PL) and two vantage points preferring the Control (NC, SP).

The highest spread of responses came at the Northern Carpark in relation to the rating between "Boring" and "Interesting". There is a strong difference between the lowest rating (Option A) and the highest (Control), which is mostly likely due to the arrangement of bicycle parking in all new design options. Generally, the most “Beautiful” locations were the Entry Plaza (M_{EP} = 3.86) and Station Interior (M_{SI} = 3.57), which scored high for all options. In the rating of “Dirty / Clean”, “Loud / Quiet”, and “Unsafe / Safe”, the vantage point locations differed strongly. In all options the Station Interior, Platforms, and South Plaza were similarly rated as “Loud” (M_{SI} = 2.49, SD_{SI} = 1.01; M_{PL} = 2.14, SD_{PL} = 1.07; M_{SP} = 1.99, SD_{SP} = 0.96). At the Entry Plaza, Control and Options A and B were also rated as “Loud”, while Option C was rated neutrally. The ratings for “Dirty / Clean” were scattered throughout all locations. The Station Interior in Control was rated as “Dirty” ($M_{Control}$ = 2.75) , whereas in Options A, B, C it tends towards “Clean” (M_A = 3.67; M_B = 3.81; M_C = 4.0). At the Northern Carpark, Control was rated as the most “Safe” (2.94) and the most “Interesting” (3.88), which is assumed to be connected to the proximity of the train station building and lack of bicycle parking at that location.

Further, the evaluation of the aspects “Loud / Quiet”, “Dirty / Clean”, and “Unsafe / Safe” prove an interesting point. These values were not directly observable in the IVE (i.e. there was no trash in a design to imply a “dirty” environment, or audio for a “loud” environment). However, because there were noticeable differences in the evaluation of these qualities depending on location and design option, participants proved to easily draw conclusions for these aspects based on the environment surrounding them.

Table 7 also shows the responses to the design option choice task (*SE-T2*). While directly comparing the design options, participants distinctly preferred Option B (48 – 61 % among the five locations). At the Southern Carpark (SC), participants found Option C competitive with Option B (with 37%), however Option C was also least preferred at two locations (PL, EP). Control was the overall least preferred design among all between-groups and locations (between 3% and 13%). Interestingly, the results of the choice task are different from the ones using the semantic differential. When looking at the criteria “Boring/Interesting” and “Ugly/Beautiful” in this task, then Control ($M_{Control}$ = 3.48) was rated as most “Interesting/Beautiful” and Option A as least (M_A = 3.23). Thus, for the future, an investigation of the suitability of the different methods for rating designs is needed.

Table 7: *SE-T1* checkpoint views and ratings results. The "Difference" column shows the deviation of each design option in comparison to Control. Checkpoints included here are also used in *SE-T2* and *DP-T1*. Percentages over checkpoint views represent the rates of preference during *SE-T2*.



6 DISTANCE PERCEPTION

The last study section concerns distance perception. Distance perception has a saturated field of research regarding the Human-Computer Interaction (HCI) differences of immersion methods (Combe et al. 2021; Kelly et al. 2017) and several aspects of architectural experience and design process. While the direct comparability of self-reported responses between real-space and VE-based surveys is still inconclusive (Maruhn et al. 2019; Li et al. 2020), HMDs have been found to provide a better facsimile of depth perception in the appraisal of object scales in contrast to alternative methods (Bazzaz et al. 2021). Architectural studies have shown that both viewing real-space environments before appraising distance in digital twin IVEs and navigating IVEs before distance perception tests increase the accuracy of results in relation to real-space distance questionnaires (Interrante et al. 2006; Kelly et al. 2018; Schneider et al. 2018). However, distance perception has not been directly studied in connection with alternative designs.

In this study section participants are asked about distance perception from various locations. The goals of this scenario are to (*DP-G1*) discover which design has the shortest appraisals of distances, to (*DP-G2*) determine the accuracy of participant responses in relation to actual distance.

6.1 Method

For brevity, the distance perception task (*DP-T1*) was performed together with the spatial experience task at four locations (SP, SC, NC, PL), as seen in Figure 5. For distance perception, the participant is asked to rate how long it would take to walk between their current position and a given destination in the IVE. The participant rates the relative distance between the values of “Very Close” and “Very Far”, as seen in Table 6. The actual distance for each location was calculated using AVEVAL-Toolbox[1] for Revit.

Table 8: DP-T1 ratings prompt.

How far away is *[location]** **?**	Very Close	◯	◯	◯	◯	◯	Very Far

*corresponding locations are: SP → Travel Centre, SI → Painted Underpass, SC → Café, NC → Kiosk, Platforms → Café, EP → Painted Underpass

6.2 Results

Responses from *DP-T1* were mapped to the shortest path distances between locations in the IVE, as seen in Figure 6. The averages of all estimations of each option were calculated, showing that Control had the shortest perceived distances ($M_{Control}$ = 3.4), directly followed by A and B (M_A = 3.5; M_B = 3.5), whereas in Option C the distances were perceived as longest (M_C = 3.7). . In terms of actual distances in each option, Control had the shortest distances on average ($M_{Control}$ =

[1] http://infarapp.architektur.uni-weimar.de/sad/

126m), followed by Option A (M_A = 128m), while Options B ($M_{B\text{-actual}}$ = 145m) and C ($M_{C\text{-actual}}$ = 141m) were slightly longer.

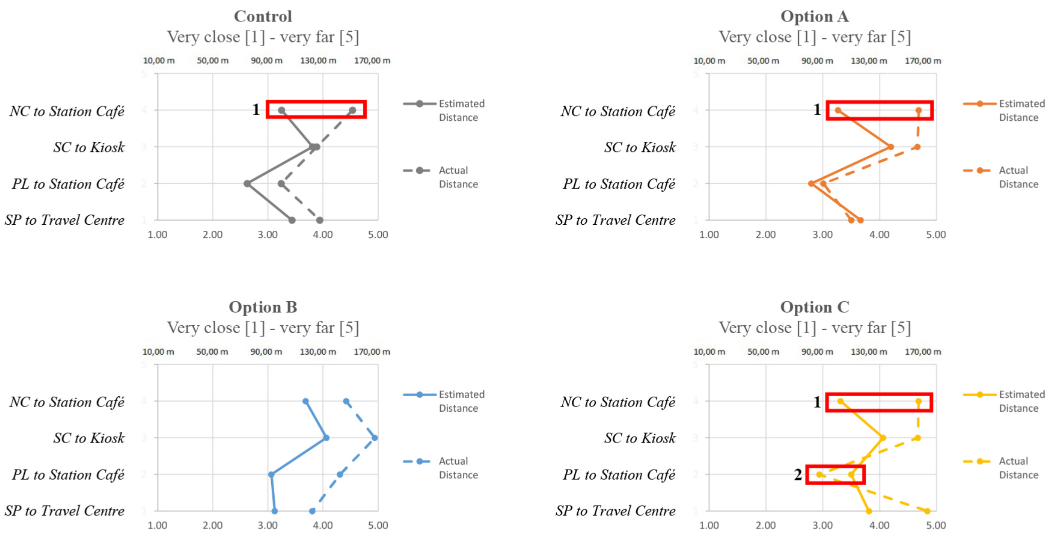


Figure 6: *DP-T1* participant distance estimations ("Very Close / Very Far") at four locations. Actual distances are mapped to the range of 5 points. Solid lines are participant estimations, while dotted lines are actual shortest distances. Points of interest are marked in red.

Two exceptional cases where distance perceptions strongly differ from actual distances are marked in Figure 6 with red boxes. The first case (1) includes the estimations at the Northern Carpark (NC) to the Station Café in Control and Options A and C. The estimations were notably shorter than the average in each of these options, while the actual distances were longer than the distances in other locations. In all three of these options the Station Cafe is not visible from NC. Interestingly, in Option B the Station Café is visible from NC and this estimation difference does not occur. The second exception case (2) is an example of overestimation at Platform 2 (PL) to the Station Café in Option C. The Station Café is also not visible in this case, which implies that direct visibility has a positive influence on the accuracy of distance perception.

7 CONCLUSION & OUTLOOK

To summarize, the focus of this study was to compare the performance of three design options against the current train station (Control) with respect to ease of orientation & route choice (RC), spatial experience (SE), waiting experience & location preference (WP), and distance perception (DP).

The RC section showed that none of the design options succeeded in drawing people to take Underpass 2 rather than Underpass 1 on their way to Platform 2. Notably, most participants did not even experience Underpass 2 as intended, and instead took Underpass 1 exclusively during the exploratory tasks. The immediate visibility, ease of cognitive path mapping, and size of Underpass 1 seems to make the path very attractive to new users. While this is valuable information, demonstrating the attractivity of one of the paths, in the future a method for properly familiarizing participants with the station is necessary. Thus, the results of this task are not easily interpretable in terms of our intended research questions. However, one of the most useful points of design development for a new train station would be a renewed planning approach which addresses the failure of Underpass 2 in all design options to match the visibility and attraction of Underpass 1. This proves that even the most unexpected refutation of assumed behaviour can have positive results in relation to design development.

In the SE section we showed two methods for assessing the spatial experience in key locations of the station. The detailed rating of spatial experience via semantic differentials revealed similar characterizations of the four designs. However, stronger differences among aspect ratings in some locations were observed (e.g. ratings at northern carpark in Control strongly differed from the ones in the designs due to the proximity of the station building and absence/presence of bike parking). Additionally, the rating of unobservable qualities (Loudness, Cleanliness, Safety) showed that participants could draw conclusions on spaces without indicating factors (such as audio, visible trash, or environmental shadows). Future research regarding conclusions based on unobservable qualities should focus on the predictability of indicating factors (i.e. what makes it appear as a “loud” environment) and the fallibility of these predictions (i.e. how accurate are these predictions, what prejudices do they contain).

The choice experiment at several locations revealed strong preferences towards one design option (B) and a strong negative response to Control. This is an interesting outcome, noting that in the semantic differential Option B did not outperform the other options, while Control performed very well in certain positive attribute ratings (“Interesting”, “Beautiful”). This deviation between spatial ratings and choice preference has been found previously (Fisher-Gewirtzman, 2019), however future research should focus on the potentials and suitability of combining different methods of spatial quality assessment.

In the WP section, participant waiting location preferences (3 per participant) were recorded and visualized within the building model. By comparing the chosen locations with the designated primary waiting spaces (one exterior, one interior), it was revealed whether the designers' intentions were met or not. The intimate waiting space of Option A and the distributed planter seating of Option C failed to become the main choice for waiting, while only the designated waiting of Option B contained a majority of chosen locations. In response to a follow-up questionnaire, participants starkly chose “Visibility” (Visual connections to platforms and station services) and “Safety” as their most important qualities when choosing a waiting location. In future analysis the sequence of the participant choices will be examined in order to understand the rank of chosen locations and wayfinding behaviour during the WP section.

Regarding the DP section, the differences of estimated distance could be observed among the design options, and the design option with the shortest estimated distances was found (Control).

By comparing these perceived distances to the actual distances, deviations were found in cases where the destination was not visible. Future research should focus on the impact of comparable architectural features on distance perception in a way that can provide a metric for accuracy.

Overall, this paper tries to show how IVE-based studies can be used to evaluate schematic designs. Therefore, different user centred aspects have been identified and study designs for several aspects were developed for evaluating potential train station designs. Furthermore, approaches for visualizing and analysing the data have been shown.

In this case, the outcome of study sections provided an observable comparison of these user centred aspects. However, the highest performing options among all sections were not the same, thus there was not one clearly superior design option. Although, the study does not conclude with an outright “best” option but does show a trend of user values which necessarily augments decision making in design.

As for noted limitations, most participants were architectural students and all participants were related to the discipline in some way. First year bachelor students of architecture were evenly distributed through all between-groups as the type with lowest prior knowledge of architectural and planning concepts. However, the inclusion of students and other participants without connections to architecture will need to become an additional focus, so that biases of those educated in architectural and urban design can be further understood.

Further implementation of user studies during the architectural design process requires defining the exact moments in the process that such evaluations are possible and useful, along with the acceptable level of differences in design features which can be compared. With such refinements, architectural studies like this can be as commonplace in schematic design and design development phases as solar, visibility, or accessibility analysis and more immediately involve user experiences into architectural design.

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REFERENCES

Arias, S., Mossberg, A., Nilsson, D., Wahlqvist, J. (2021) 'A Study on Evacuation Behavior in Physical and Virtual Reality Experiments', *Fire Technology*, Sept. doi: 10.1007/s10694-021-01172-4

Arthur, P. and Passini, R. (1992) *Wayfinding: People, Signs, and Architecture*. Ontario: McGraw-Hill.

Bazzaz, S.A., Fioravanti, A., Coraglia, U.M. (2020) 'Depth and Distance Perceptions within Virtual Reality Environments – A Comparison between HMDs and CAVEs in Architectural Design', *eCAADe*, 38 (1), pp. 375-382. Doi: 10.14279/depositonce-10568.2

Clark, D.A., Walker, K. (2020) 'Veterans in Classrooms: Post Traumatic Stress, Seating Preferences, and Achievement', *Journal of Veterans Studies*, 6 (1), pp. 259-270. Doi: https://doi.org/10.21061/jvs.v6i1.153

Combe, T., Chardonnet, J., Merienne, F., Ovtcharova, J. (2021) 'CAVE vs. HMD in Distance Perception', IEEE Conference on Virtual Reality and 3D User Interfaces, pp. 448-449. Doi: 10.1109/VRW52623.2021.00106

Dalton, S., Marshall, P., Dalton, R. (2010) 'Measuring environments for public displays: a Space Syntax approach', *CHI 2010*, pp. 1-6. Doi: 10.1145/1753846.1754066

De Crescenzio, F., Bagassi, S., Starita, F. (2021) 'Preliminary user centred evaluation of regional aircraft cabin interiors in virtual reality', *Scientific Reports*, 11:9662. Doi: https://doi.org/10.1038/s41598-021-89098-3

Deuble, M., de Dear, Richard. (2014) 'Is it hot in here or is it just me? Validating the post-occupancy evaluation', Intelligent Buildings International, 6(2), pp. 112-134. doi: 10.1080/17508975.2014.883299

Dijkstra, J., Van Leeuwen, J.P. (2003) 'Evaluating Design Alternatives Using Conjoint Experiments in Virtual Reality', *Environment and Planning B: Planning and Design*, 30, pp. 357-367. Doi: 10.1068/b12932

Dunston P.S., Arns L.L., Mcglothlin J.D., Lasker G.C., Kushner A.G. (2011) An Immersive Virtual Reality Mock-Up for Design Review of Hospital Patient Rooms. In: Wang X., Tsai J.JH. (eds) Collaborative Design in Virtual Environments. Intelligent Systems, Control and Automation: Science and Engineering, vol 48. Springer, Dordrecht. doi: .org/10.1007/978-94-007-0605-7_15

Ewart, I.J., Johnson, H. (2021) 'Virtual Reality As A Tool To Investigate And Predict Occupant Behaviour In The Real World: The Example Of Wayfinding', *Journal of Information Technology in Construction*, 26, pp. 286-302. Doi: 10.36680/j.itcon.2021.016

Gath-Morad, M., Aguilar, L., Dalton, R. (2020) 'cogARCH: Simulating Wayfinding by Architecture in Multilevel Buildings', *SimAUD 2020*, pp. 27-34.

Fang, D., Nayga, R., West, G., Bazzani, G. (2020) 'On the Use of Virtual Reality in Mitigating Hypothetical Bias in Choice Experimets', *American Journal of Agricultural Economics*, 00(00): 1-20. Doi: 1–20; doi:10.1111/ajae.12118

Feng, Y. (2022) 'Wayfinding beahviour in a multi-level building: a comparative study of HMD VR and Desktop VR', *Advanced Engineering Informatics*, 51:101475. Doi: 10.1016/j.aei.2021.101475

Fisher-Gewirtzman, D., Yoisifof, R., Dalyot, S. (2019) 'Visual Experience Route Planning For Urban Environments', *Proceedings of the 12th Space Syntax Symposium*, 492-2, pp. 1-12.

Flacke, J., Shrestha, R., Aguilar, R. (2020) 'Stengthening Participation using Interactive Planning Support Systems: A Systemic Review', *International Journal of Geo-Information*, 9 (49), pp. 1-34. Doi: 10.3390/ijgi9010049

Gou, Z., Khoshbakhat, M., Mahdoudi, B. (2018) 'The Impact of Outdoor Views on Students' Seat Preference in Learning Environments', *Buildings*, 8 (96), pp. 1-15. Doi: 10.3390/buildings8080096

Heydarian, A, Carneiro, J.P., Gerber, D.J., and Becerik-Gerber, B. (2015) ‘Immersive virtual environments, understanding the impact of design features and occupant choice upon lighting for building performance’, *Building and Environment*, 89, pp. 217-228. doi: 10.1016/j.buildenv.2015.02.038

Heydarian, A., Pantazis, E., Carneiro, J.P., Gerber, D., Becerik-Gerber, B. (2015) ‘Towards Understanding End-user Lighting Preferences in Office Spaces by Using Immersive Virtual Environments’, *ASCE International Workshop of Computing in Civil Engineering*, pp. 1-8. Doi: 10.1061/9780784479247.059

Interrante, V., Anderson, L., Ries, B. (2006) 'Distance Perception in Immersive Virtual Environments, Revisited’, *IEEE Virtual Reality 2006*. Doi: 10.1109/VR.2006.52

Irshad, S., Perkis, A., Azam, W. (2021) 'Wayfinding in Virtual Reality Serious Game: An Exploratory Study in the Context of User Perceived Experiences’, *Applied Sciences*, 11:7822, pp. 1-19. Doi: 10.3390/app11177822

Jelic, A., Tieri, G., De Matteis, F., Babiloni, F., Vecchiato, G. (2016) 'The Enactive Approach to Architectural Exerience: A Neurophysiological Perspective on Embodiment, Motivation, and Affordances’, *Frontiers in Psychology*, 7 (481), pp. 1-21. doi: 10.3389/fpsyg.2016.00481

Kelly, J.W., Hammel, W.W., Siegel, Z.D. (2017) 'Perceived Space in the HTC Vive’, ACM Transactions on Applied Perception, 15 (1), 2:1-16. Doi: 10.1145/3106155

Kelly, J.W., Cherep, L.A., Klesel, B., Siegel, Z.D., George, S. (2018) ‘Comparison of Two Methods for Improving Distance Perception in Virtual Reality’, *ACM Transactions on Applied Perception*, X (X), 1:1-12. doi: 10.1145/3165285

Keskin, Z., Chen, Y., Fotios, S. (2015) 'Daylight and Seating Preferences in Open-Plan Library Sapces’, *International Journal of Sustainable Lighting*, 1, pp. 12-20. Doi: 10.26607/ijsl.v17i0.12

Keszei, B., Balasz, B., Losonczi, A., Dull, A. (2019) 'Space Syntax’s Relation to Seating Choices from an Evolutionary Approach’, *Periodica Polytechnica Architecture*¸ 50 (2), pp. 115-123. Doi: https://doi.org/10.3311/PPar.14251

Kim, M.J., Cho, M.E. (2017) ‘Measurement of User Emotion and Experience in Interaction with Space’, *Journal of Asian Architecture and Building Engineering*, 16(1), pp. 99-106. doi: http://doi.org/10.3130/jaabe.16.99

Krösl, K., Bauer, D., Schwärzler, M. *et al*. (2018) ‘A VR-based user study on the effects of vision impairments on recognition distances of escape-route signs in buildings’, *Vis Comput*, 34, pp. 911-923. doi: 10.1007/s00371-018-1517-7.

Kuliga, S. (2016) ‘Evaluating User Experience and Wayfinding Behaviour in Complex, Architectural Environments – Towards a User-centred Approach of Building Usability’, PhD Dissertation to Alber-Ludwig-University Freiburg.

Kuliga, S., Nelligan, B., Dalton, R.C., Marchette, S., Shelton, A.L., Carlson, L., Hölscher, C. (2019) ‘Exploring Individual Differences and Building Complexity in Wayfinding: The Case of the Seattle Central Library’, *Environment and Behavior*, 51 (5), pp. 622-665. doi: 10.1177/0013916519836149.

Li, H., Mavros, P., Krukar, J. (2020) 'The effect of navigation method and visual display on distance perception in a large-scale virtual building’, *Cognitive Processing*, 22 (4), pp. 1-22. Doi: 0.1007/s10339-020-01011-4

Loyola, M., Rossi, B., Montiel, C., Daiber, M. (2019) ‘Use of Virtual Reality in Participatory Design’, *eCAADe 37*, 1 (2), pp. 449- 454.

Maruhn, P., Schneider, S., Bengler, K. (2019) 'Measuring egocentric distance perception in virtual reality: Influence of methodologies, locomotion and translation gains’, *PLoS ONE*, 14 (10), pp. 1-24. Doi: https://doi.org/10.1371/journal.pone.0224651

McIntosh, J., Marques, B., Harkness, R. (2020) 'Simulating impairment through virtual reality’, *International Journal of Architectural Computing*, pp. 1-12. Doi: 10.1177/1478077120914020

Moloney, J., Globa, A., Wang, R., Khoo, C. (2019) ‘Principles for the application of mixed reality as pre-occupancy evaluation tools (P-OER) at the early design stages’, *Architectural Science Review*, 63:5, pp. 441-450. Doi: 10.1080/00038628.2019.1675138

Natapov, A., Fisher-Gewirtzman, D., Parush, A. (2022) ‘Architectural features and indoor evacuation wayfinding: The starting point matters’, *Safety Science*, 145, 105483. doi: 10.1016/j.ssci.2021.105483

Naz, A., Kopper, R., McMahan, R.P., Nadin, M. (2017) ‘Emotional Qualities of VR Space’, *IEEE Virtual Reality 2017*. Doi: 10.1109/VR.2017.7892225

Preiser, W. (2001) ‘The Evolution of Post-Occupancy Evaluation: Toward Building Performance and Universal Design Evaluation’, *Learning From Our Buildings: A State-of-the-Practice Summary of Post-Occupancy Evaluation* ,pp. 9-22.

Radaczewska, P., Schneider, S., Kuliga, S. (2019) ‘Exploring Urban Experiences: Two Case Studies’, *Proceedings of the 12th Space Syntax Symposium*, 432, pp. 1-11.

Rid, W., Haider, W., Ryffel, A., Beardmore, A.B. (2018) 'Visualisations in Choice Experiments: Comparing 3D Film-sequences and Still-images to Analyse Housing Development Alternatives’, *Ecological Economics*, 146, pp. 203-217. Doi: http://dx.doi.org/10.1016/j.ecolecon.2017.10.019

Ryffel, A.N., Rid, W., Gret-Regamey, A. (2014) ‘Land use trade-offs for flood proection: a choice experiment with visualizations’, *Ecosystem Services*, 10, pp. 111-123. Doi: http://dx.doi.org/10.1016/j.ecoser.2014.09.008

Schneider, S., Maruhm, P., Bengler, K. (2018) 'Locomotion, Non-Isometric Mapping and Distance Perception in Virtual Reality’, *ICCAE 2018*. Doi: 10.1145/3192975.3193022

Schneider, S., Kuliga, S., Weiser, R., Kammler, O. (2017) ‘VREVAL: A BIM-based Framework of User-centered Evaluation of Complex Buildings in Virtual Environments’, *eCAADe*, 36, pp. 833-842.

Peijin, H., Samarasinghe, D.A.S., Liu, C., Jelodar, M.B., Playne, D., Baghaei, N. (2021) ‘Supporting Decision-Making in the Construction and Property Sectors through Persuasive Virtual Reality’, *Construction Education: Live the Future*, AUBEAC 2021, pp. 185-194.

Städler, S. (2021) 'The Integration of Virtual Reality into the Design Process‘, PhD Dissertation, TU-Munich.

Toskovic, O., Kovac, V., Sovilj, D. (2021) 'Lost in projection – Implicit features experience of 3D architectural forms and their projections’, *Acta Psychologica*, 213:103239, pp. 1-9. Doi: 10.1016/j.actpsy.2020.103239

Van Hagen, M. (2011) ‘Waiting Experience at Train Stations’, PhD Disseration, Universiteit Twente.

Van Hagen, M., Bron, P. (2014) ‘Enhancing the experience of the train journey: changing the focus from satisfaction to emotional experience of customers’, *Transportation Research Procedia*, 1, pp. 253-263. Doi: 10.1016/j.trpro.2014.07.025

Van Leeuwen, J.P., Hermans, K., Jylhä, A., Quanjer, A.J., Nijman, H. (2018) ‘Effectivenss of virtual Reality in Participatory Urban Planning’, *MAB 18*. Doi: 10.1145/3284389.3284491

Vuong, K.A., Cain, R., Burton, E., Jennings, P. (2013) ‘A mixed methods approach to identify and predict people’s perception of the design in healthcare waiting environments’, *ICIASDR 2013*, pp. 1-11.

Westerdahl, B. et al. (2006) ‘Users‘ evaluation of a virtual reality architectural model compared with the experience of the completed building’, Automation in Construction, 15, pp. 150-165. doi: 10.1016/j.autcon.2005.02.010

Wölfel, M., Hepperle, D., Purps, C.F., Deuchler, J., Hettmann, W. (2021) ‘Entering a new Dimension in Virtual Reality Research: An Overview of Existing Toolkits, their Features and Challenges’, *iXperience Lab – intelligent interaction & immersive experience Lab*. Doi:

Yuan, S., Zhang, H. (2018) ‘Correlation between aesthetic perception and spatial cognition during exploration in traditional Chinese villages’, *Preedings of the 12th Space Syntax Symposium*.

Zhang, M., Ke, J., Tong, L, Luo, X. (2021) ‘Investigating the influence of route turning angle on compliance behaviors and evacuation performance in a virtual-reality-based experiment’, *Advanced Engineering Informatics*, 48:101259, pp. 1-15. Doi: 10.1016/j.aei.2021.101259

Zomodorian, K., Parva, M., Ahrari, I., Tavana, S., Hemyari, C., Pakshir, K., Jafari, P., Sahraian, A. (2012) 'The effect of seating preferences of the medical students on educational achievement', *Med Educ Online 2012*, 17:10448. Doi: 10.3402/meo.v17i0.10448