Virtual Reality
https://doi.org/10.1007/s10055-022-00673-z

ORIGINAL ARTICLE

Exploring the future building: representational effects on projecting oneself into the future office space

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Received: 13 April 2021 / Accepted: 21 June 2022

Abstract

While virtual reality (VR) has been explored in the field of architecture, its implications on people who experience their future office space in such a way has not been extensively studied. In this explorative study, we are interested in how VR and other representation methods support users in projecting themselves into their future office space and how this might influence their willingness to relocate. In order to compare VR with other representations, we used (i) standard paper based floor plans and renders of the future building (as used by architects to present their creations to stakeholders), (ii) a highly-detailed virtual environment of the same building experienced on a computer monitor (desktop condition), and (iii) the same environment experienced on a head mounted display (VR condition). Participants were randomly assigned to conditions and were instructed to freely explore their representation method for up to 15 min without any restrictions or tasks given. The results show, that compared to other representation methods, VR significantly differed for the sense of presence, user experience and engagement, and that these measures are correlated for this condition only. In virtual environments, users were observed looking at the views through the windows, spent time on terraces between trees, explored the surroundings, and even "took a walk" to work. Nevertheless, the results show that representation method influences the exploration of the future building as users in VR spent significantly more time exploring the environment, and provided more positive comments about the building compared to users in either desktop or paper conditions. We show that VR representation used in our explorative study increased users' capability to imagine future scenarios involving their future office spaces, better supported them in projecting themselves into these spaces, and positively affected their attitude towards relocating.

Keywords Immersive VR environments · User engagement · Sense of presence · User experience · Job relocation

1 Introduction

The collaboration between people from the fields of architectural design, building construction, and various other stakeholders such as investors and future occupants is pivotal for the successful completion of construction projects. However, communication failures and misunderstandings can easily compromise such projects. In recent decades, computational technologies such as building information modelling (BIM) have been used to assist the construction industry (Azhar 2011; NBS 2016). BIM is defined as the "use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" (ISO 2018).

Although not strictly necessary (Leon 2014), a BIM process can run throughout the entire life cycle of a construction project from the early conceptual design phase well into the time when the building structure is already in use. The conceptual design phase (activities of function formulation, concept generation, concept organisation, concept evaluation, and concept improvement) is a very important stage in the entire process in order to bring everyone on board to

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Published online: 21 July 2022

understand all the future implications of the finished project (Meng et al. 2020). However, when it comes to future office buildings, the number of studies involving future occupants in the conceptual design phase is scarce (some notable examples include (Westerdahl 2006; Frost and Peter 2000)). This is despite the fact that job relocation is one of the most stressful events people face and an employee's willingness to relocate depends on several factors including, amongst others, their perceptions and attitudes (Szpunar 2010).

Currently, the most commonly used formats of representation in the conceptual design phase are two-dimensional sketches and computer-aided design (CAD) models (NBS 2016). One of the biggest challenges of this phase is to clearly convey ideas in three dimensions (3D) through two-dimensional (2D) sketches and drawings. While professionals are used to mentally translating allocentric[1] to egocentric views (Kuliga and James 2020), it can be hard for someone outside the design world, to fully grasp the real implications of allocentric representations presented during pre-occupancy evaluation – i.e. before the building is constructed (Frost and Peter 2000). Therefore, the representation used in the conceptual design phase has a significant impact on and defines the efficiency of the information sharing, understanding of the architectural design, the overall quality of the design process, and the final outcome (Acock 1985). Virtual reality (VR) has consistently been shown to be efficient in pre-occupancy evaluation (Bassanino et al. 2010; Chandrasegaran 2013; Frost and Peter 2000; Westerdahl 2006; Kuliga and James 2020).

One of the significant features of VR environments is their ability to facilitate the sense of presence (Schwind et al. 2019; Benyon et al. 2014; Sanchez-Vives and Slater 2005; Witmer and Singer 1998) – the feeling of being or operating in a place by projecting oneself into that space while being physically present in another location (Banos 2004; Regenbrecht et al. 1998). VR thus supports users in gaining a critical perspective of 3D virtual models by experiencing the sensation of moving around the space, understanding its composition, viewing details from various angles (allo- and egocentric), and reacting accordingly, to shape the next steps of construction projects. Most commonly, moving is achieved either by walking or teleporting. Compared to the latter, walking delivers a more immersive experience (Slater et al. 1995; Usoh et al. 1999), reduces cognitive load (Zanbaka 2005) and VR sickness (Llorach et al. 2014; Jaeger and Mourant 2001). While teleporting is considered risk free (especially in confined physical spaces), and it reduces the possibility of VR sickness (Keshavarz et al. 2015), it lacks optical flow, which lowers the sense of presence (Bowman et al. 1997), and may cause spatial disorientation (Bowman et al. 1997; Bakker et al. 2003).

With current advancements in VR technologies, many architectural studios and construction companies have extended their conventional 2D technical drawings into 3D immersive environments (Dajana 2019). It has been shown, that the use of immersive VR environments in the design and construction industry facilitates better visual perception, and forms conditions for collaborative decision-making and problem-solving in the conceptual design phase (Dunston et al. 2011; Frost and Peter 2000). Nevertheless, there is little known about how such representation of the office space or the involvement of future occupants in the process, affects their capability to project themselves into the future office space and willingness to relocate. Thus, the research questions that led our study are:

- RQ1 How does the representation method influence the projection of participants into their future office space in aspects such as, their engagement (RQ1a), sense of presence (RQ1b), and user experience (RQ1c)?
- RQ2 How does the representation method influence the perception of and imagining oneself in the future office space?
- RQ3 Are there any correlations between the participants' engagement, sense of presence, and user experience of the functional space, and can observing them together better support the results obtained?

In order to answer these questions we teamed up with the InnoRenew Centre of Excellence (CoE) institute that was in the initial phase of the construction process of a new office building for researchers and administrators. We developed three different representation methods: (i) the conventional paper-based 2D floor plans and rendered images of the future building (paper condition), (ii) a virtual environment experienced on a computer monitor with the highly-detailed 3D representation of the future building (desktop condition), and (iii) the same environment experienced with a head-mounted display (HMD) (VR condition). In particular, this explorative study aimed to answer our research questions by analysing the patterns of exploration, user engagement, and by analysing questionnaires for the sense of presence and user experience.

The main contributions of this article are: (i) an explorative study of how future occupants project themselves into their future office space based on the representation method of the virtual building (paper, desktop, VR), (ii) how this influences their attitudes towards the building and moving, and (iii) a comprehensive analysis of variables including user engagement, sense of presence, user experience as well as correlations between them in the context of (i) and (ii).

[1] For the purpose of this work we use the term allocentric view as one which is a top-down view of an object, such as a map (Kuliga and James 2020; Cartillier et al. 2021; Dey et al. 2014).

The next section covers the research background on VR in architecture, the engagement and sense of presence within VR, and job relocation. Section 3 describes the research method with three different conditions (paper, desktop and VR), participants and the study procedure. The results section (5) is followed by discussion (4) and conclusion (6).

2 Research background

VR in architecture and construction provides the conditions for greater collaboration among stakeholders (Bassanino et al. 2010; Berg and Vance 2017; Fernando et al. 2013), allows more solid design decisions, and supports identification of the design and development issues that might not be identified efficiently in conventional ways (Bassanino et al. 2010; Dunston et al. 2011; Frost and Peter 2000). In addition, VR can provide designers and researchers with reliable user behaviour during human-building interactions (Bassanino et al. 2010; Kuliga and Thrash 2015; Heydarian et al. 2014), and can enhance safety training (Xie et al. 2006) by providing high levels of immersion that can optimise the learning process (Faas 2014). With the use of VR, both the cost and time spent on decision-making by building physical mock-ups used in the design review process can also be significantly reduced (Majumdar et al. 2006; Juan et al. 2018). Overall, VR provides users with a realistic perception of the design (Fernando et al. 2013) as well as the ability to "simulate the experience of moving through and interacting with the virtual world as if it was real" (Bassanino et al. 2010, p. 3).

Most of the studies of VR in architecture and construction focused on cognitive or affective aspects separately (e.g. (Berg and Vance 2017)), and used either simple abstract representations of space (non highly realistic) or environments based on semi-immersive projections (Schnabel and Kvan 2003; Westerdahl 2006; Ruddle et al. 1999). Related works to ours include a comparison between VR and a real building (Westerdahl 2006) and desktop and VR (Ruddle et al. 1999). The former study revealed that VR supports the decision-making process about the future workplace. The latter study showed that users in VR moved quicker and had a more accurate sense of relative straight-line distance. However, these works did not focus on how representation methods helped future occupants project themselves into the future office space.

We took the engagement, sense of presence, and user experience as the measures of projecting oneself into a future office space. We present these measures in the following subsections together with the related work on job relocation, stress and projecting oneself into the future.

2.1 User engagement

User engagement has been defined and studied in several contexts (Semiha 2019; Fredricks et al. 2011; Topu and Goktas 2019; Schaufeli 2013; Pierce et al. 2017). It is a dynamic, complex and multi-dimensional process (Schaufeli 2013; Pierce et al. 2017; Topu and Goktas 2019) composed of (intertwined) users' internal indicators such as feelings (affective dimension), thinking, reasoning, learning, etc. (cognitive dimension), and observable actions such as performing various activities, interacting with a system, navigating, exploring, etc. (behavioural dimension) (Appleton et al. 2008).

Kearsley and Shneiderman have stressed that engagement can be obtained without technology, but technology opens up novel possibilities that are hard to achieve in real life (Kearsley and Shneiderman 1998). Accordingly, research in this area has explored engagement with images (Frantzidis 2010), video clips (Murugappan et al. 2008; Yazdani et al. 2009), music (Takahashi and Akinori 2003; Koelstra 2012), and real-life scenarios (Katsis 2008; Weber 2019). With the advancement and availability of VR technologies, this medium has also been used and evaluated in a number of studies as a means of presenting emotional stimuli (Moghimi 2016; Violante et al. 2019; Birenboim 2019; Cebeci et al. 2019).

One of the foci of our first research question (RQ1a) is *How does the representation method of users' future office space influence participants' engagement?* Previous work has shown that when studied separately, affective, cognitive and behavioural dimensions affect user engagement in different contexts (Pierce et al. 2017), and that studied together they affect the engagement in an educational context (Topu and Goktas 2019). There is a lack of studies of these three dimensions studied together in the architectural design comparing different representation methods. We hypothesise that the method of representation will affect all dimensions of user engagement of future occupants while projecting themselves into their future office space.

2.2 Sense of presence and user experience

User Experience describes the subjective, holistic, situated sentiments of users towards a service, software or product in use (Marc 2010; ISO 2010). It thus includes a person's perception, emotion, cognition, motivation and behaviour – aspects that are inter-playing with the context of use (the place, time (before, during and after an interaction), people, and other objects) (idem). This understanding of user experience has expanded beyond the realm of human-computer interaction (HCI) and it is also used in architectural design (Krukar et al. 2016). HCI evaluation methods have been for example implemented to find functional deficiencies in buildings as products (Christoph 2006).

Recent user experience models divide user experience into two dimensions: pragmatic, that includes the objective properties of the service, software or product in use, and hedonic properties, that describe users' perception of these (Law et al. 2007). In the past decade both dimensions have been measured with questionnaires such as the popular UEQ (Schrepp et al. 2017; Schrepp 2019). It has been suggested that user experience in VR is affected also by the sense of presence (Steuer 1992) and the evidence supports a relation between the two (Busch et al. 2014; Brade 2017). The sense of presence can be described as the feeling of being present or immersed in a given setting upon the perception of it (Gifford 2007; Steuer 1992; Witmer and Singer 1998).

It's the immersion in VR enabled by stereoscopy, wide field of view, and a high degree of interactivity that facilitates a higher sense of presence (Dunston et al. 2011; Castronovo et al. 2013). Furthermore, since the human perception process is driven on inputs from different sensors (Gifford 2007; Steuer 1992), the more detailed the interface of the immersive environment, the more likely it is to enable a higher sense of presence (Bertol 1996). In an architectural setting, VR can be considered as the medium that enables users to explore the insides and outsides of a future building through its virtual 3D representation (Steuer 1992).

The importance of sense of presence as an outcome of immersive 3D VR environments has been highlighted in existing literature (Barfield and Weghorst 1993; Witmer and Singer 1998), and multiple questionnaires to measure it have been suggested (Witmer and Singer 1998; Mel et al. 1998; Usoh et al. 1999; Usoh and Catena 2000). The questionnaires used today have been carefully designed and refined over more than two decades. However, the use of questionnaires alone might not be enough to identify differences between the sense of presence in various representation methods (Mel et al. 1998; Slater and Martin 1993), as the sense of presence appears to be affected by a combination of environmental and personal factors (Witmer and Singer 1998).

Despite existing research on the user experience and sense of presence in 3D VR environments, there are still gaps in the knowledge (Renner et al. 2013). Several studies have focused on finding differences and similarities in (measuring) the sense of presence in VR and the real world (Westerdahl 2006). It has been confirmed that despite receiving different stimuli from VR and the physical surroundings, VR can still increase the sense of presence as users can filter information and focus by using selective attention (Witmer and Singer 1998; Pashler 1999). The comparison between playing a game on a flat display and a head-mounted display also demonstrated that there is a difference in experiencing the space and the perceived degrees of the sense of presence between the two (Federica et al. 2019). Nevertheless, immersive gaming presents a complex task-based activity, while the focus of this study is on a free-style exploration of the environment. Differences in sense of presence between desktop and VR have also been found in education (Makransky et al. 2019; Zhao et al. 2020).

The second and third foci of our first research question (RQ1b and RQ1c) is *How does the representation method of the model of their future office space influence the participants' sense of presence and user experience in it?* Based on previous studies we expect that the more immersive the environment, the better the user experience, and higher the degree of the sense of presence.

2.3 Job relocation

Job relocation has been mostly studied in the context of individual employees and is often associated with stress (Martin 2000), characterised by changes in physical environment, daily routines and social circles. The willingness to relocate depends on familial or background factors (single-earner marriage), personal factors or perceptions and attitudes (relocation and normative beliefs, self-efficacy, relocation policy satisfaction, organisational commitments and desire for career progress), spouse attitudes (willingness to relocate and relocation policy satisfaction), social factors (disruption of social contacts, social support), organisational factors (job characteristics) and others (Eby Lillian and Russell 2000; Luo and Cooper 1990; Maike and Margenfeld 2015). It is thus not surprising that relocation is often faced with resistance (Eby Lillian and Russell 2000).

When it comes to company relocation the studies are more scarce (Sagie et al. 2001). Relocation preparation (Robin 1999) as well as involvement of all employees (Chevi 2018) can simplify the relocation and reduce resistance. As mentioned, when a company is building new premises one of the possibilities is to involve employees by letting them participate from the design process onward and experience the building upfront. Involving users in the design process can help them project themselves into the future.

Projecting oneself into the future is a vibrant research area (see (Klein 2013) for a comprehensive review) also known by other terms such as future-oriented mental time travel or episodic future thought. It is the ability to imagine and simulate personal events that may potentially take place (Szpunar 2010). Recent studies have shown that past experiences are closely related to the ability of imagining one's future (Szpunar 2010; Schacter 2012). It is thus expected that exploring different representation methods with the same level of details but with different degrees of immersion will variously affect the experience and thus provide a different basis for imagining one's future. We hypothesise that the more

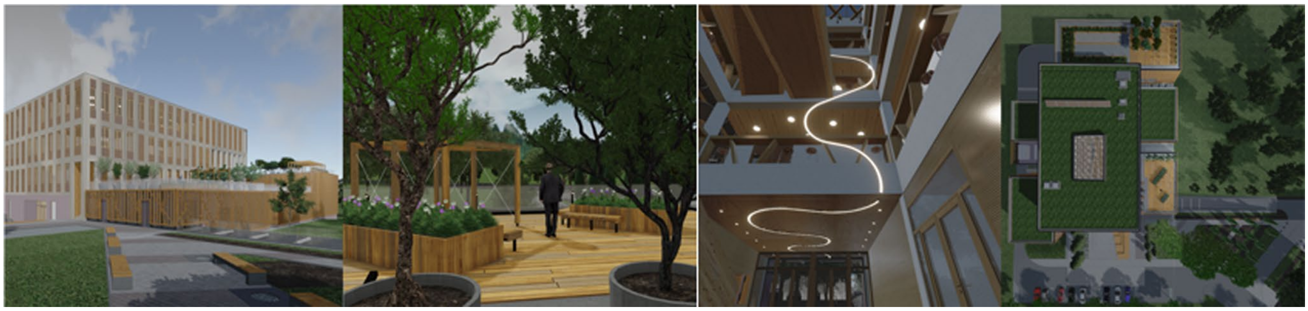


Fig. 1 Scenes from the Innorenew CoE building 3D environment

immersive the experience, the easier it will be for the future occupants to imagine how moving will affect them.

3 Research method

In order to investigate our research questions, we teamed up with architects and investors working on the future InnoRennew CoE[2] headquarters. The management of the institute agreed to participate in the development of the virtual experience and the explorative study, which happened in the final stages of the design process when high-fidelity mock-ups of the actual building were expected. This section describes the study conditions, study procedure, participants' sampling, data collection and how it was analysed.

3.1 Study conditions

We created three different conditions, each employing a different representation method of the future office space: (i) a paper based folder with 2D floor plans and rendered figures of the future office – paper condition, (ii) a 3D virtual experience presented on a regular computer monitor – desktop condition, and (iii) the same 3D virtual experience presented on the head-mounted display (HMD) – VR condition.

For the virtual experience, we used the 3D model of the building created by the architects using Autodesk 3ds Max, and developed it into a 3D virtual environment using the Unity 3D game engine. During the entire process we worked together with architects who provided their input on different aspects of the experience in order to make it as close as possible to how they envisioned it. Some of the scenes of the virtual experience are visible in Fig. 1. The building is four stories high (referred to as ground floor and floor 1 to 3) with floors connected by an internal staircase. Besides allowing the exploration of building interiors, the experience also allowed outdoor exploration up to 50 metres away from the entrance side of the building and up to 5 metres around other sides.

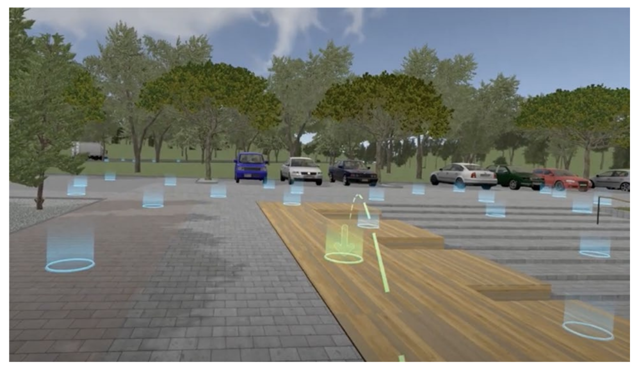


Fig. 2 Teleport points in the virtual environment

Desktop and VR conditions differed only in rendering type (non-stereoscopic vs. stereoscopic), navigational device (computer mouse vs. HTC controller), and display type (Tobii pro spectrum 24-inch computer monitor vs. HMD Tobii Pro HTC Vive). For both conditions we used the same high-performance desktop computer with two graphics processing units. Participants navigated through virtual space using a controller or mouse to teleport (a risk free navigation (Keshavarz et al. 2015)) from one point to another. The distance between teleport points was a maximum distance allowed by the HTC Vive controller in order to minimise the navigation effort and allow users to quickly move around the space (see Fig. 2).

For the paper condition, we used the content prepared by architects to be presented to stakeholders involved in the project (investors, various engineers, etc). Since we planned to present this content to future occupants of the building we removed some detailed information intended for engineers. Such information could overwhelm participants and they could miss important information asked in the questionnaires (described below). Together with architects we decided to leave in the plans the measures of the building,

[2] https://innorenew.eu/.

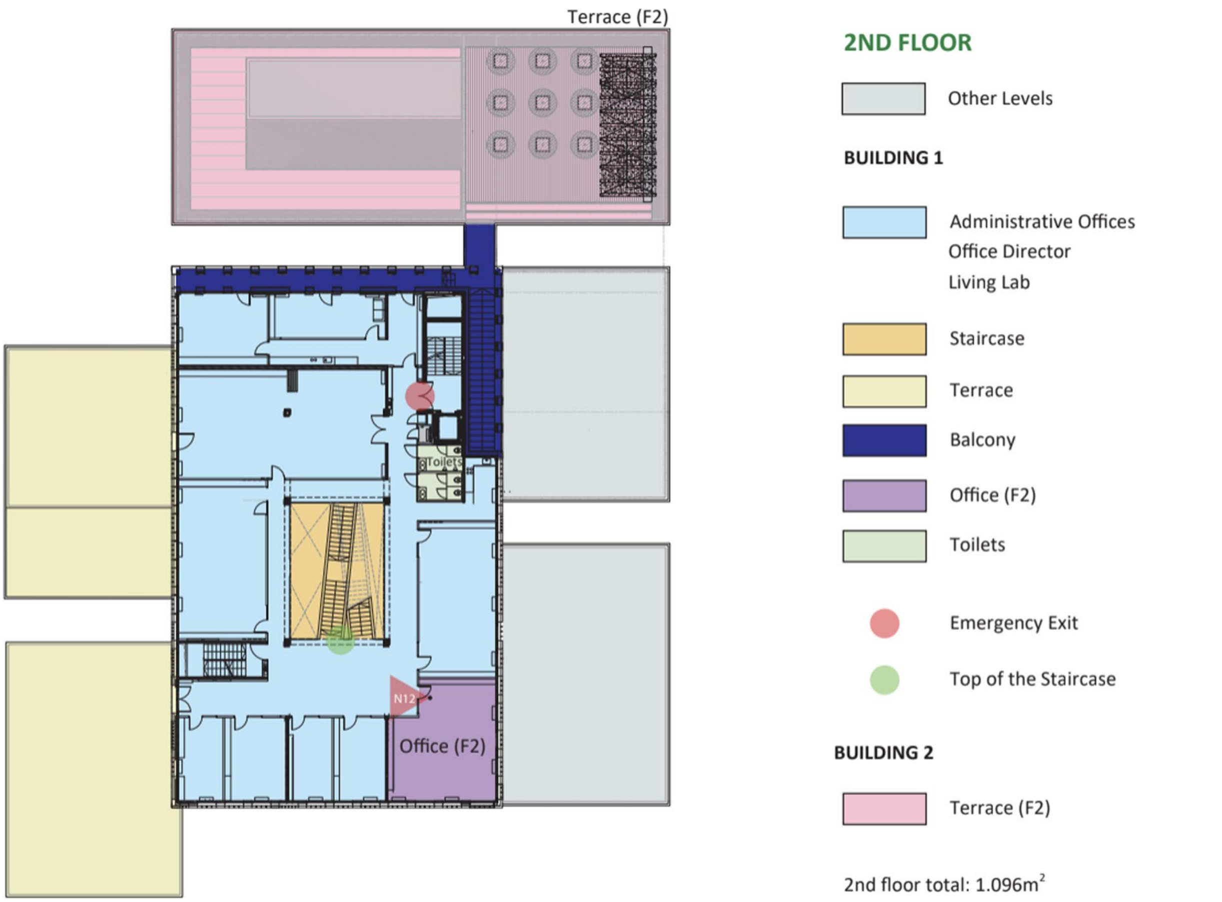


Fig. 3 One of the 2D floor plans from the Innorenew CoE building

names of rooms and areas, and to highlight 12 areas that architects labelled as interesting (see Fig. 3 as an example). We also replaced the original rendered images with the ones from the virtual environment looking at the same scenes from the same angles in order to have the same quality of renders as in the virtual experience.

3.2 Participants

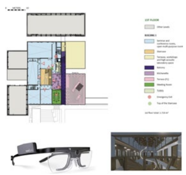
In total, 29 participants volunteered to participate in the study: 10 in paper (4 female), 9 in desktop (5 female), and 10 in VR condition (5 female). All participants were 25 to 55 years old ($\bar{x} = 37$) and were either employed by the InnoRenew CoE (80%) or otherwise linked to the institute. The voluntary response sampling method was used by advertising the study on the internal mailing list of the institute since we wanted to study future occupants of the building.

3.3 Study procedure

Participants were first asked to sign a consent form and fill in a short pre-questionnaire about the current office space and moving to a new building. Participants have been randomly assigned to conditions. After a five minute training session, we calibrated the eye-tracking device and attached the electrodermal activity sensors (EDA or galvanic skin response (GSR)). The data from these sensors are out of scope of this paper and will be published in a separate publication. Participants were then instructed to freely explore the representation method for up to 15 minutes without any restrictions or tasks given in order to imitate how users actually explore a physical building. To facilitate navigation, information boards and signs were included in the environment as in an actual building (the paper condition had labels of rooms and spaces included).

Participants were then given a post-questionnaire about their experience and attitude towards moving, two standard questionnaires – a sense of presence (SUS) (Mel et al. 1998; Usoh and Catena 2000; Usoh et al. 1999) and a user experience questionnaire (UEQ) (Schrepp et al. 2017) – and a questionnaire to assess participants' spatial perception of the environment. These questionnaires were answered without the access to the representation method. Next, participants answered also a size and capacity perception questionnaire

Table 1 Study procedure for each condition

Time	Paper condition	Desktop condition	VR condition
	Consent form & Pre-questionnaire (current building, moving expectations)		
5 min training	Floor plan, rendered images of outdoor of the building with plan reading instructions.	Demo virtual experience with instruction on how to teleport using the mouse.	Demo virtual experience with instruction on how to teleport using the controller.
	Attach EDA sensor on participants' wrist & calibrate the eye-tracker		
Up to 15 min exploration			
	Post-questionnaire (representation experience & moving expectations), SUS, UEQ and Spatial perception questionnaires		
	Size and capacity perception questionnaire with the use of the representation method		
Up to 15 min exploration	VR condition	VR condition	/
	Post-questionnaire (demographics, VR experience, sight problems, sense of orientation)		

with the use and help of the representation method they previously explored. The results of the last two questionnaires will also be published in a separate publication.

After completing the questionnaires, participants assigned to the paper and desktop conditions were invited to explore the virtual building using the HMD VR. At the end, participants were asked to fill in a short post-questionnaire with demographic questions, questions about previous experience with VR technology (3D games or virtual experiences), sight problems and sense of orientation. The overall procedure of the study is shown in Table 1.

3.4 Data collection

In all conditions we captured eye-tracking and EDA data (as mentioned, these will be published in our later work). For paper and desktop conditions facial expression data were also collected to measure affective engagement and consequently user experience (due to the use of HMD we could not do it in VR) (Kapoor et al. 2003). For both desktop and VR conditions, path tracking data were logged by the system as a part of behaviour engagement (for the paper condition this was not possible due to representation specifics). Cognitive engagement was not measured since the study did not involve any task to solve. In all conditions users completed all questionnaires mentioned.

We used Affectiva iMotions (iMotions n.d.) real-time facial expression analysis (FEA) software for the data acquisition and expression analysis with the AFFDEX face detection (Farnsworth 2019). The software is based on the Facial Action Coding System (FACS), which codes specific combinations of action units (contractions of facial muscles) into the six basic emotions (Farnsworth 2019; McDuff et al. 2016): joy, anger, surprise, fear, disgust and sadness. Due to the relevance to the study, we have taken into account only joy and anger, to which we will refer from here on as positive and negative emotions. Affectiva iMotions provides emotion evidence scores corresponding to the probability of the presence of each emotion between 0 (absent) and 100 (present). A threshold suggested in the literature for an emotion being present or absent is between 50 and 70 (Farnsworth 2019). In order to avoid noise, we decided on a threshold for the presence of emotional response at a minimum expression duration of one second (1s), added an immediate median correction of the last three (3) samples of the emotion evidence score, and set the threshold at 70 (Weber 2018; Farnsworth 2019).

To measure the sense of presence we used the common Slater-Usoh-Steed (SUS) six questions questionnaire (Mel et al. 1998; Usoh and Catena 2000; Usoh et al. 1999), which measures: (i) the sense of being in the VR environment, (ii) the extent to which the VR environment becomes the dominant reality, and (iii) the extent to which the VR environment is remembered as a 'place'. For measuring the user experience we used the short version of the User Experience Questionnaire (UEQ-S) (Schrepp et al. 2017; Schrepp 2019) with eight items/questions. The first four represent pragmatic qualities (Perspicuity, Efficiency and Dependability) and the last four hedonic qualities (Stimulation and Novelty) (Schrepp 2019).

3.5 Data analysis

In all statistical analysis we used a significance level $p - value = 0.05$ and a restrictive confidence interval (CI) of 95%. Each data set collected in the study was first checked for normality using the Shapiro-Wilk normality test (Shapiro and Wilk 1965). The statistical significance between study conditions (between-subject design) was examined using the Kruskal-Wallis non parametric test (Kruskal-wallis test 2008), and if significance was found we used the Mann-Whitney test (Neuhäuser 2011) to determine where the significance occurred. The resulting $p < 0.05$ are reported as statistically significant. All boxplots use a 1.5xIQR (interquartile range) rule and Tukey's fences (Lisa 2016) for whiskers and identified outliers. Asterisk notation is used in figures to visualise statistical significance (not significant: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$, and ****: $p < 0.0001$).

We also conducted a power analysis to check and validate the results and findings of the study. We calculated the effect size (Cohen's d) for each data set collected (Cohen 1988), selected the minimum effect size (Cohen's $d = 1.553$) and estimated the statistical power ($1 - \beta = 0.9$) of data to check whether the type II error probability (β) is within an acceptable range for a given sample size ($n = 9$ per group) and a significance level ($\alpha = 0.05$). The estimated power value 0.9 shows that with the given sample size, we can have a 90% chance that we correctly reject the null hypothesis with a significance level 0.05.

Since all independent variables (engagement (behavioural, affective), sense of presence, and user experience) are, based on the literature, related to one another (see Sections 2.1 and 2.2) we believe that observing them together can better support the results. We have thus used the Pearson multiple correlation test (Plackett 1983) to find out whether there were any correlations between these variables.

4 Results and findings

This section is divided into four subsections. The first focuses on user engagement, the second on the sense of presence and user experience, the third describes the correlation between these measures, and the fourth subsection presents the results from the pre- and post-questionnaire about moving.

4.1 User engagement results

In this section we present results divided in two parts: behaviour and affective engagement (see Section 2.1).

4.1.1 Behavioural engagement

Behavioural engagement covers observable behaviour, which includes among others conscious navigation, involvement observation, time spent, the amount and type of interaction with the environment, etc. Overall, participants in the paper condition spent on average five (5) minutes to freely explore their representational method compared to 10 in the desktop and 14 in the VR conditions. For further behavioural engagement we turned to observations for the paper condition and logs for the other two conditions. In particular, we looked at the paths traversed and time spent at different interesting areas.

Figure 4 shows the average amount of time spent at each teleport point. In the VR condition, participants navigated through more teleport points and spent more time outside of the building compared to the desktop condition. This happened on *Terrace 1*, *Staircase 1-2* (1st floor), *Terrace 2*, the passage between *Terrace 2* and the building (2nd floor), and in the *Open space* (3rd floor). It thus shows higher engagement in these areas. An interesting observation is that in both desktop and VR conditions participants moved towards the windows wherever this was possible and looked at the view outside. We observed this in the *meeting room* on the first floor, in the *office room* on the second floor, and in the *open space* on the third floor, which is visible by circles close to the windows.

Figure 5 illustrates the navigation patterns and density of the average time in seconds for the overall experience for desktop and VR conditions. In the VR condition, participants explored the outdoors (the side of the building with the entrance including the road) a lot more compared to desktop condition. There is no big difference in the indoor navigation pattern between the conditions. Nevertheless, participants in VR showed higher behavioural engagement (more time spent in the environment, more teleportation points explored, more time spent in more interesting areas) compared to the desktop condition. In the paper condition, participants mostly just scanned the plans and spent more time on rendered images. Comparing the overall time, however, they spent twice as less time in the desktop and three times in the VR condition.

4.1.2 Affective engagement measures

We did a facial expression analysis for the paper and desktop conditions to determine the emotional engagement of participants as described in Sect 3.4. Since the duration of exploration in each condition and the number of emotions

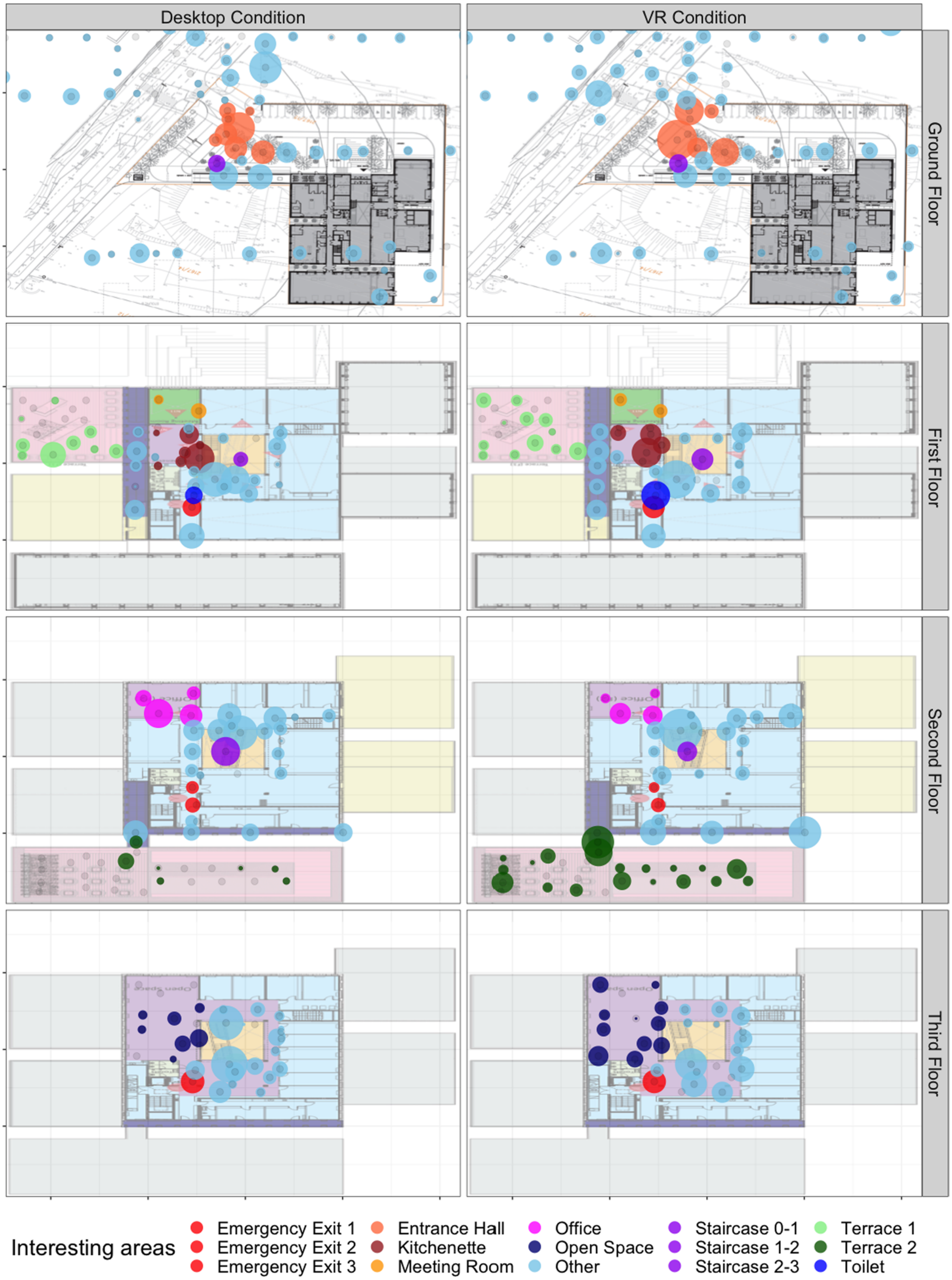


Fig. 4 The average amount of time in seconds spent at each teleport point in each interesting area for desktop and VR conditions. The bigger the circle, more time spent at that point

Fig. 5 Navigation pattern and density of the average time in seconds for the overall experience presented on a hexbin map

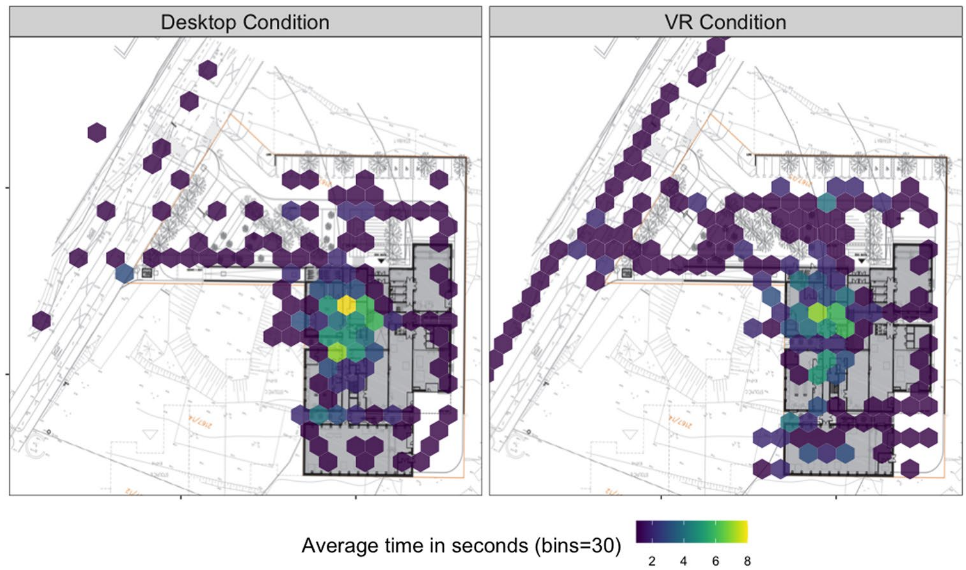
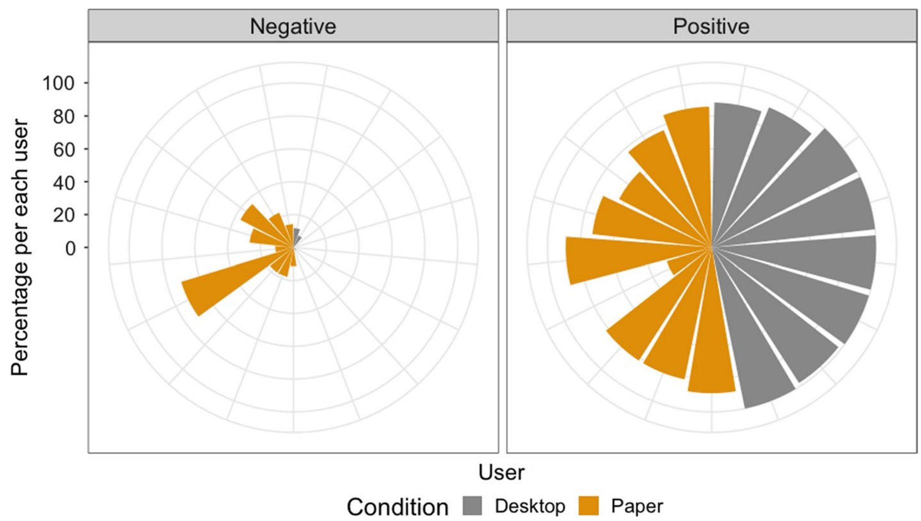


Fig. 6 Percentage of positive and negative emotions per user in paper and desktop conditions. The longer the cone, the more emotional responses of that kind were registered



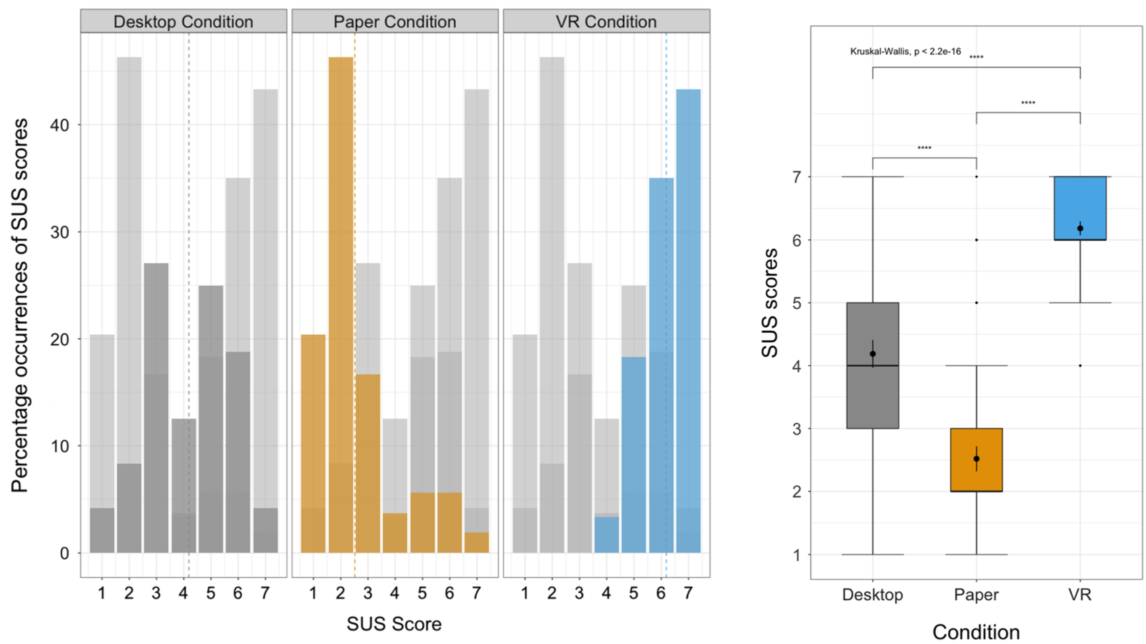
registered varied between participants, we present the values in percentages – this is the number of each emotion registered out of all the emotions registered for a specific participant. Fig. 6 shows a slight presence of negative emotions in the paper condition and more positive emotions registered in the desktop condition.

While the mean percentage of registered positive emotion instances is significantly higher than negative emotion instances in both conditions, it is even higher in the desktop compared to the paper condition (desktop $\bar{x} = 97.3\%$, CI [94.6, 100]; paper $\bar{x} = 74.4\%$, CI [64, 84.8]). In the paper condition, the system registered nearly 25% of negative emotion instances, while this number is low in the desktop condition. The Mann-Whitney nonparametric test shows a significant difference in emotions registered for both positive and negative emotions when comparing desktop and paper conditions (positive $p = .0065$, negative $p = .0065$).

Table 2 Descriptive statistics for both emotions considered together (positive and negative). The percentage difference from the overall average in the last column was calculated as such $100 * (Total\_average - Study\_condition\_average)/Total\_average$

Study Condition	Average for both emotions	SD	Error 95 CI	% difference from overall average
Desktop	25.0	13.7	7.9	+ 10.5%
Paper	30.5	19.6	10.8	− 9.4%
Total	27.9	16.9	6.8	

Descriptive statistics for both emotions are summarised in Table 2. High standard deviations indicate the widespread of emotions. Consequently, the mean value is a poor indicator of individual performance, but considering the entire data it gives and indication on the variations in



(a) Distribution of mean values of SUS answers on a 7-point scale for each condition.

(b) Study condition influence on emotions registered.

Fig. 7 SUS scores

emotions registered between study conditions. The Mann-Whitney nonparametric test did not show statistical significance ($W = 111.5$, $p = 0.2682$)

4.2 Sense of presence and user experience

This sub-section reports on the results from the Slater-Usoh-Steed (SUS) and the User Experience Questionnaire (UEQ).

4.2.1 Sense of presence (SUS) questionnaire

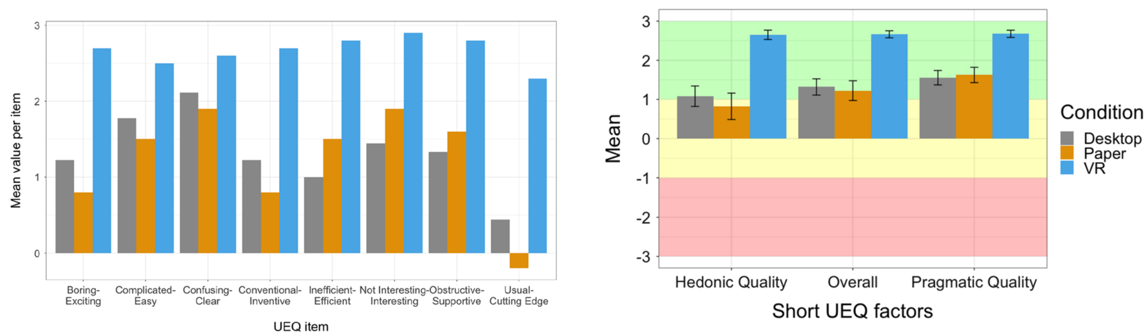
The answers to the six SUS questions are reported on a 7-stage Likert scale (1 low, 7 high). Figure 7a illustrates the mean values from the SUS questionnaire and distribution. The answers for the VR condition are skewed towards the left with the mean value > 6, which means that in this condition the sense of presence was very high compared to the other two conditions. The distribution of the paper condition is skewed towards the right with the mean value < 3, which means that the sense of presence was lowest here. The sense of presence for the desktop condition had a more varied distribution with a mean value of around 4.

A Kruskal-Wallis nonparametric test showed a significant difference ($\chi^2 = 93.531$, df = 2, $p = 2.2e - 16$), indicating that the condition influenced the sense of presence. The pairwise comparison using a Mann-Whitney-Wilcoxon nonparametric test (desktop-paper: $p = 1.7e - 07$, desktop-VR: $p = 4.5e - 11$ and paper-VR: $p = 1.4e - 16$) revealed significant differences between all the pairwise study conditions (Fig. 7b).

4.2.2 User experience questionnaire

The answers to UEQ questions/items are also reported on a 7-stage Likert scale, where the first four items represent pragmatic qualities (Perspicuity, Efficiency and Dependability) and the last four the hedonic qualities (Stimulation and Novelty). The results are assigned a value between −3 and 3 as follows: if the item starts with a negative term, a 1 on the 7-stage scale becomes a −3, while if the item starts with a positive term, the 1 becomes a +3. These adjustments are kept throughout the rest of the analysis.

The mean values are calculated and rated according to (Schrepp et al. 2017; Schrepp 2019). Every UEQ scale belongs to either a 'negative evaluation' with a mean value $-3 \leq \bar{x} < -0.8$, a 'neutral evaluation' with a mean value between -0.8 and +0.8, and a 'positive evaluation' with a mean value $+0.8 < \bar{x} \leq +3$. This can be applied to single items or factors (pragmatic and hedonic). The calculated mean for every item is shown in Fig. 8a. There is only one negative evaluation for the paper condition (for the question usual-cutting edge) and no negative evaluation for desktop and VR conditions.



(a) Mean values per item/question.

(b) Mean values of UEQ factors (pragmatic and hedonic) and all item/question together (overall).

Fig. 8 UEQ scores

Figure 8b shows the mean values per factor and the corresponding confidence intervals. In addition, the mean value of all the items is given as an overall user experience value. Pragmatic ($\bar{x} = 2.67$) and hedonic ($\bar{x} = 2.65$) qualities, as well as overall user experience ($\bar{x} = 2.66$) are perceived as extremely positive in the VR condition. The mean values of all the factors are also clearly above the threshold value of 0.8 in the desktop condition (pragmatic - $\bar{x} = 1.55$, hedonic - $\bar{x} = 1.08$ and overall - $\bar{x} = 1.31$). The mean of the hedonic factor ($\bar{x} = 1.31$), which represents the Stimulation and Novelty, is below the threshold value of 0.8 in the paper condition.

4.3 Correlations between user experience, sense of presence and engagement

A Pearson multiple correlation test (Plackett 1983) was used to find out if there were any correlations between user experience, sense of presence, and engagement (behavioural, affective). We found correlations between *user experience – sense of presence* ($r = 0.72$, $p = 0.009$) and *user experience – behavioural engagement* ($r = 0.69$, $p = 0.010$) in the VR condition. There were no significant correlations between user experience, sense of presence, and engagement for desktop and paper conditions.

4.4 Attitude towards moving

In the pre-questionnaire, participants were asked about the current office premises and about the attitude towards moving into the new building. Only 4% of participants rated the current premises as bad, 11% as excellent, 83% as good and 2% do not know. The reasons mentioned against the current premises were: not enough light in the office (in the old city centre buildings are in close proximity), air quality, sharing an office with other people, improvised offices and lack of parking spaces. There were more reasons to like the offices such as convenient location, close proximity to the sea side, wooden furniture, plenty of light, creative teammates, and good equipment.

The pre-questionnaire also revealed some concerning comments about the new building being located in a different town. Most of the participants like the current town as it is bigger and it offers a variety of facilities in close proximity, which is not the case with the new building. More than half of the participants complained that they will need to commute to the new location as they live near the current one. Just one person mentioned that they live close to the new building and one liked its remote location. One person raised the fact that their children are going to school in the current town and the move will require a bit of flexibility from the family. A few mentioned that they will miss seeing researchers from the university and two assumed they will be split between the new and the old location, which would, in their opinion, make meetings a challenge.

When asked in a pre-questionnaire about how they expect the new office building will compare to the current one 93% of the responses claimed it will be better (3.5% the same and 3.5% do not know). Positive reasons included dedicated offices and labs, and that the whole company will be together as they are residing in several buildings at the moment. These results did not significantly change in the post-questionnaire.

When asked in the post-questionnaire whether the expectations of moving to a new building changed 90% of participants in the VR condition answered yes, compared to 37.5% in desktop and 66.7% in the paper condition (see Table 3). The positive attitude in VR could also be seen in rating the VR experience as excellent in 90% of the cases (50% in desktop and 44% in paper).

Table 3 Post-questionnaire results of quantitative questions

How would you rate the experience of the future InnoRenew office facilities?					
Condition	**Poor**	**Below average**	**Above average**	**Excellent**	**I don't know**
VR			10%	90%	
Desktop			50%	50%	
Paper			44%	44%	12%
Did this experience change your expectations about how your future office facilities will look like?					
Condition	**Yes**	**No**	**I don't know**		
VR	90%	10%			
Desktop	38%	62%			
Paper	67%	33%			
How confident would you feel about moving around in a normal working day?					
Condition	**Lost**	**Confident**	**Very confident**	**I don't know**	
VR		30%	70%		
Desktop		50%	50%		
Paper	12%	44%	44%		

Participants in the VR condition provided 22.5% more answers to open ended questions than in desktop and 32.5% more than in the paper condition. In, VR participants provided 16 positive comments about offices and the building, 6 complemented greenery and surroundings (including parking), and two close proximity to colleagues (11, 1, and 2 in desktop and 8, 1, and 2 in paper condition, respectively). The expanded list of positive reasons for moving included: modernity, new equipment, wooden furniture, spacious common areas, natural sunlight, flexibility, eco-friendliness, clean design, cosy and pleasant environment, working together with colleagues, and availability of parking spaces. Regarding the confidence of moving about in the new facilities, positive comments focused on how well participants understood the space, and in particular participants provided 10 positive comments in VR, 7 in desktop and 5 in the paper condition. Only in the latter we received comments such as *"I felt lost"* and *"through the maps it's hard to understand the locations"*, which points to the fact the allocentric view is not an optimal representation for some people.

It could be argued that regardless of the representation method, participants who were offered more information about the future office building are likely to find more positive reasons for moving. However, participants in desktop and VR conditions were exposed to the same detailed virtual environment and yet, in the VR condition more comments in general were received. Another reason might be the time spent in the VR condition (on average 40% more) and thus exposing participants to more information. But the results show that in both conditions participants visited the same places and used similar traversing patterns. Overall, the VR condition has elevated a more positive attitude towards moving.

5 Discussion

We designed an explorative study to compare how future occupants are able to project themselves into the future office space when presented with a different representation method of the real future building: (i) a paper-based presentation with floor plans and rendered images of the building as used by architects (paper condition), (ii) a highly-detailed 3D virtual model of the future building experienced on a computer monitor (desktop condition), and (iii) the same virtual environment experienced with a head mounted display (VR condition). The impact of the representation method was measured through user engagement, sense of presence and user experience.

5.1 User engagement

Our RQ1a was *How does the representation method of the model of the future office space influence engagement?* Based on (Appleton et al. 2008), engagement can be divided into affective, cognitive and behavioural. We hypothesised that the representation method will affect engagement.

5.1.1 Behavioural engagement

We measured behavioural engagement for desktop and VR conditions by observing where users spent their time and how much time they spent in different locations. We could not observe this in the paper condition; nevertheless, we could observe users being more interested in renders (egocentric view) than in floor plans (allocentric view). This was expected as floor plans can be hard to mentally translate to an egocentric view for non professionals (Kuliga and James 2020), which has also been found in this study. In desktop and VR conditions participants spent a similar amount of time in different spaces with some exceptions. In the VR condition, participants spent more time in front of the building exploring the road to and from the building, and on outdoor terraces. In both conditions, participants also spent a considerable amount of time at the windows admiring the view.

It is well known that individual and architectural factors can directly and indirectly contribute to physical and psychological discomfort in an office space (Alan 1989). The time spent staring out of the windows and observing the views should not come as a surprise, since attractive window views are known for reducing discomfort at work (van Esch 2019) and consequently improving home life (e.g. sleep) (Aries et al. 2010), provide a natural source of light (Wong 2017), while closer proximity to windows reduces health problems and complaints among occupants (Küller and Wetterberg 1996; Yildirim et al. 2007).

A similar explanation can be found for spending time in outdoor spaces (terraces and in front of the entrance). These spaces are filled with greenery, which provides an opportunity for recovery from mental fatigue and are generally beneficial to human health (Berman et al. 2008; Kaplan 1995). The time spent in the VR condition "walking" to and from the building can be attributed to higher immersion with the environment surrounding users. Moving in space has been pointed out as one of the pivotal affordances in VR (Zhao et al. 2020; Horvat et al. 2019) and an important finding of our study was that people spent nearly 40% more time moving in VR compared to the desktop. There is a potential to explore these observations in further studies.

5.1.2 Affective engagement

We measured affective engagement through analysis of facial expression for desktop and paper conditions. The amount of positive feelings was higher in the desktop condition. Significantly more negative feelings were recorded in the paper condition, while these were almost absent in the desktop condition. Affective engagement is directly linked to the sense of presence and emotions. For example, experience in anxious or relaxing VR environments increased these emotions as well as the sense of presence (Riva 2007). Studies on learning in VR also report on higher emotional arousal in VR compared to content presented on a computer monitor (Makransky et al. 2019; Parong and Mayer 2020). Higher affective engagement of the desktop condition can be explained by the pleasant environment presented by the aforementioned greenery (Berman et al. 2008; Kaplan 1995). We could not measure affective engagement in the VR condition; although, since the virtual environment was the same in the desktop condition as in the VR condition, and since users spent considerably more time in the VR condition, we can assume that the VR condition would show even higher affective engagement based on the increased behavioural engagement and sense of presence.

5.2 Sense of presence and user experience

Research questions RQ1b and RQ1c were *How does the representation method influence the sense of presence and user experience?* We hypothesised, based on previous studies, that the more immersive the environment the higher the level of the sense of presence. We measured the sense of presence with the SUS questionnaire. As expected, users in the VR condition reported the highest sense of presence, while users in the paper condition the lowest. The significant difference has been confirmed between all three study conditions. This was not surprising for the paper condition since it does not offer an immersive experience (Juan et al. 2018). Despite experiencing the same virtual environment, the significant difference between desktop and VR conditions should not come as a surprise since several studies already confirmed that compared to desktop, VR supports a higher sense of presence (Makransky et al. 2019; Zhao et al. 2020; Federica et al. 2019).

As both desktop and VR conditions used the same highly-detailed virtual environment, we expected a lesser difference between the two. This is because prior work in architecture claimed that the more detailed the environment, the higher the sense of presence (Bertol 1996); however, these works did not mention the representation method. Another reason was that our study just involved casual exploration of a future building compared to other studies examining different representation methods (VR vs desktop) that involved complex tasks such as playing a video game (Federica et al. 2019) or navigating and understanding a non-detailed virtual environment (Ruddle et al. 1999).

Despite expectations, our study shows that even if users do not engage in complex tasks, and they just move around a virtual building, there was a significant difference between the desktop and the VR representation method. This is in line with aforementioned studies (Federica et al. 2019; Ruddle et al. 1999) and it also indicates that the sense of presence might not be so much related to the task at hand but more on the level of detail (Bertol 1996) and immersivness provided by the display.

In our study, only the display (high definition computer monitor vs. head-mounted display (HMD)) facilitated this difference. Previous studies have shown that HMDs can enhance focused and selective attention (Cho et al. 2002; Amprasi et al. 2022), and consequently increase the sense of presence, by cutting visual stimuli from the physical environment. To even further leverage the sense of presence researchers have explored small additions such as a breeze or adjusted temperature in the physical surroundings (Ranasinghe et al. 2017). It would be interesting to investigate if such additions would increase the sense of presence even for the desktop condition. In addition, since previous studies report a lower sense of presence with teleportation vs walking, future studies could also look at this aspect.

User experience in VR has been often looked at in relation to the sense of presence or even defined by it (Steuer 1992). It was thus expected that the paper condition would receive least positive values. Despite using the same virtual environment for desktop and VR, the VR condition acquired twice the levels of positive scoring for both hedonic and pragmatic qualities of user experience. This finding further supports the results for a higher sense of presence in VR.

5.3 Correlation between measures

We have also investigated how different variables are correlated and how they could be combined in order to more accurately present engagement, sense of presence, and user experience for each study condition. This contrasts to the existing body of VR research in architectural design that often looks at these aspects individually. Our results show correlations in VR between *the sense of presence and user experience*, which was to be expected since the two are considered related (Steuer 1992), as well as between *user experience and behavioural engagement*. Interestingly, there were no correlations found in the other two conditions. Despite using the same environment in desktop and VR, the latter supports significantly higher degree of immersion. It thus highly affects the sense of presence, which affected the user experience. However, further studies are required to explore any causation between the aspects measured.

5.4 Implications for research and practice

A recent review of the VR landscape in architecture and construction defined six areas where VR supports the field: stakeholder engagement, design support, design review, construction support, operations and management support, and training (Delgado et al. 2020). Our study focuses on under explored aspects of stakeholder engagement. VR has already been used to engage with various stakeholders (investors, potential clients, public), giving them an opportunity to participate in pre-occupancy evaluation, examine built-assets at real-scale or align their expectations with the actual design (Pejic et al. 2017; Juan et al. 2018; Kini and Shilpa 2019; Frost and Peter 2000).

However, the focus of our study was on a particular group of stakeholders – the future occupants. As the company leadership already decided to move to new premises, this group did not have much say in this, contrasting our work with other studies of future occupants, which focused on VR as a support of better understanding of, and the decision-making process concerning their future workplace (Westerdahl 2006; Frost and Peter 2000). For this reason we were interested in how involving future occupants in the process by showing them different representation methods (paper, desktop, VR) would help them project themselves into their future office space and how this might influence their attitudes towards moving. In our study we have shown that VR as a representation method increases the sense of presence, user experience and engagement and that these measures are correlated.

The study also shows that for this particular group of users, the building itself is not the only important part of the experience. The exterior of the building as well as the greenery around it proved to be almost as essential. Participants enjoyed moving outdoors and observing the building from various sides. Several even took "a walk" to the building, which is one of the key aspects of VR (Jiayan and Sensibaugh 2020; Horvat et al. 2019). Moreover, the majority of participants stopped at the windows and admired the view. Overall, the VR experience influenced participants to add more positive comments about moving, compared to other conditions. Even participants that have initially experienced a less immersive representation method (paper and desktop) provided positive comments after experiencing the VR. These comments further emphasise the importance of feedback for people in leadership positions.

The following results are speculative due to the explorative nature of the study presented but point out interesting research directions. It has been shown that past experiences support imagining hypothetical future scenarios and that memory can flexibly recombine past and novel experiences into novel simulations of possible future events (Szpunar 2010; Schacter 2012; Pascal 2008; Suddendorf and Corballis 2007). The ability to imagine details of future scenarios also supports one's effective coping with future events through emotional regulation and appropriating current activities (Brown 2002). VR might thus provide a viable approach in supporting "one's effective coping with future events" such as a job relocation – a life event often associated with stress (Martin 2000)). Previous findings also show that imagining future scenarios is associated with optimism bias (Tali 2011). Besides other measures used, the amount of additional positive comments received after experiencing the VR condition might thus also indicate that VR better supports simulating possible futures, compared to the other two representation methods. These speculative results open up possible new research directions in different fields to further investigate the effects of VR on projecting oneself into future scenarios. For example, it has been shown that representing potential future selves in a virtual environment can motivate people to make better food choices in the future (Kuo et al. 2016).

The main VR challenges listed in recent literature include insufficiently detailed virtual environments, the necessity of supervision and hardware, the ease of use, and the sense of isolation (Delgado et al. 2020; Juan et al. 2018). In contrast with older studies with future occupants (Westerdahl 2006; Frost and Peter 2000), we have built a highly-detailed virtual environment, used high-end hardware and teleportation as navigation techniques to avoid any technical and other issues that might contribute to user discomfort. None of the participants reported any problems related to VR. However, such a project needs a large time commitment for implementation (Yung and Khoo-Lattimore 2019) (4 months of work in our case), which might limit the capability of implementing such an environment for a lot of projects as it involves significant financial investment. The claims that VR environments can cut the costs of time spent on decision-making and the cost of building physical mock-ups (Majumdar et al. 2006; Juan et al. 2018) remain largely unproven as VR is not yet part of the essential toolchain in the fields of architecture, engineering, and construction. In spite of all the benefits presented in this study and other studies mentioned in the paper, VR remains useful and nice to have but not essential, yet.

We also did not encounter any issues with the ease of use, despite the fact that 87% of our participants have never played 3D video games, and 64% never experienced VR before. As for the supervision, hardware, and sense of isolation, they still remain a challenge. Although some attempts in this direction have been made (Du 2018; Kunert 2020) the current systems still do not allow for large scale collaborations in VR. Nevertheless, as technology advances such limitations might be resolved with a broader commercial uptake.

5.5 Limitations and future research directions

One of the main limitations of our study is the number of participants. At the time of the study the Innorenew CoE institute had 39 people employed. Some were not eligible to participate in the main study (architects and people in leadership positions). The majority of other employees have participated and observations were consistent among each condition. Nevertheless, we have shown that the type II error is within the acceptable range. This paper does also not discuss how different methods of representation affects the spatial perception as this is beyond the scope of the topic presented here. Such an analysis, results and discussion is the subject of future work.

6 Conclusion

The focus of the explorative study presented in this paper was to investigate how different representation methods (VR, desktop, paper) influenced how future occupants project themselves into the future office space and to explore their willingness to relocate. The results show a statistically significant difference for the sense of presence, user experience and user engagement in VR compared to the paper and desktop conditions. Users were also observed looking at the views through the windows, spent time on terraces surrounded by the greenery, extensively explored the surroundings, and even "took a walk" to work. We also received more positive comments about the building after experiencing the VR condition. We argue that experiencing VR better supported people in projecting themselves into their future office spaces, increased their capability to imagine future scenarios, and positively affected their attitude towards moving. The study, experimental design, results and discussion presented here can inform future studies and aid the current development of systems for exploring future buildings.

Funding The authors acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement 739574) under the Horizon2020 Widespread-Teaming program and the Republic of Slovenia (Investment funding of the Republic of Slovenia and European Union of the European Regional Development Fund). We also acknowledge support from the Slovenian research agency ARRS (program no. P1-0383, J1-9186, J1-1715, J5- 1796, J1-1692, and IO-0035).

Code availability Not applicable

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

Ethics approval The authors declare that they received the ethics approval to conduct the research.

Consent to participate The authors declare that they received the consent from all the participants before participating in the study.

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