Cross-case analysis on the integration of extended reality (XR) with the design and planning of the built environment

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Abstract

This paper serves as an introduction to the Ph.D. research project through four recent case studies, which are then utilized towards a multiple case study analysis in the form of a cross-case report. The focus of the study is on Extended Reality (XR) technology as a means of qualitative user data in the design and planning of the built environment. The Ph.D. project is based on a literature review on status of smart cities and related architecture and design research, currently calling for more integrated case study data on developing participatory design practices for cities. The goal of the thesis is therefore to contribute to the field of smart cities research in highlighting the potential role of extended reality (XR) technology in creating more immersive and interactive urban environments which may enhance democratic decision-making ability among citizens. We note how XR created the ability for users to understand design proposals at scale, and to interact with proposals and create their own designs on-site. The use of XR impacted final design outcomes in all studies, suggesting XR as a potential tool for increasing a qualitative understanding of user experience in the design and planning process. We conclude with a discussion on opportunities and barriers for the implementation of XR in participatory urban planning, pointing to the need for a more coordinated and holistic approach to both XR technology development and planning policy if the technology is to be developed such use.

Author keywords

Extended Reality, Mixed Reality, Interaction Design, Architecture, User Experience, Virtual Environment, Phenomenology, Design Theory

Introduction

Urbanization, digitization, and the development of democratic and participatory decision-making processes are all powerful contemporary trends which require new research. As cities are increasingly more populated and complex to manage, city governments search for tools to conduct planning of urban areas in an efficient and sustainable way (Montes, 2020). One new tool, Extended reality (XR) - a frontier technology consisting of augmented (AR), virtual (VR) and mixed (MR) reality (Milgram & Kishino, 1994) - allow for 3d objects and models to be placed in a real-life context and interacted with by users, thus offering obvious use cases for architecture and planning domains (Kato & Billinghurst, 2002; Barfield, 2017; White and Nikolic, 2018; Hillmann, 2021). In current literature, researchers claim numerous benefits of introducing XR to design and planning, but also identify the need to determine the best practice in design curricula (Milovanovic et al., 2017;Martín-Gutierrez et al., 2017; Hakkila et al., 2018; Mohamed et al, 2019). In parallel, the real estate and construction sectors, not traditionally been known for being innovative, have slowly been ramping up innovation, particularly because operators and users were keen to see more data and analytics applied to the user experience and reporting (Olander & Landin, 2005; Grunevald et al., 2022), signaling a transition from 'product push' to 'client first' concepts and particularly the use of XR in the design process. In this way, the focus on client-first user experience concepts that embody deep insight into user expectations and interactions could influence on the urban planning sector which heavily relies on the real estate sector to enact its plans.

Here it is important to note that the UN Habitat recommendation focuses specifically on integrated XR with governments and municipalities to further study how XR influences not only business domains but also the fundamentals of democratic decision-making in planning (UN Habitat, 2019), particularly in response to the UN Sustainability goal (SDG) 11 of increasing democratic participation in planning. However, while XR is being extensively researched, few cases attempt to implement XR in real-life planning and design scenarios with municipalities and state actors. For example, a Piumsomboon et. al (2018) study found that while AR has been studied extensively over the last few decades, most studies are conducted in laboratory settings and do not involve pilot testing. Here, finding solutions to the interweaving of new digital tools in response to unprecedented urban growth, population expansion, and an increased focus on sustainability, is increasingly relevant (Ertio, 2015) perhaps even more than technology research alone. In addition, managing the complexity of decision-making amongst an increasingly digital citizenry, creates both challenges to traditional techniques and methods, while opening pathways to new ways in which to engage users with planning through digital tools (Landry, 2016). Therefore, the lack of integrated case work forms the basis for new research.

Materials and methods.

To research the problem of XR implementation into design and planning thoroughly, the thesis utilizes a multiple case studies approach consisting of a series of cases studying the use of XR is participatory design and planning with different user groups and in different types of settings. Here, we will present a multiple case study analysis based on the Yin (2013) multiple case study design model, based on four of the most recent cases in the Ph.D. project. Often deployed in design research methods, a multiple case study is a research study on multiple cases to understand the similarities and differences between the cases and to be aimed to generalize conclusion over several units (IGI, 2021). The design of such a study through multiple case design is a research methodology in which several instrumental, bounded cases are examined using multiple data collection methods. For the Ph.D. project, following the Yin (2013) model, this meant not only conducting several cases but designing the cases structure in relation to each other, but also developing common data collection strategies in order to draw cross-case conclusions regarding the use of XR in the design and planning of the built environment more generally.

Following the development of theory, the Yin (2013) model calls for the design of a data collection protocol and the selection of cases. For multi-case research, the cases need to be similar in some way, for example the study of a program in many sites (Stake 2006). As displayed in table 1., we selected cases with different types of design and planning schemes – which were then allocated with choice of XR hardware and software deemed appropriate for the case. Each case studied a specific user group typical to that type of scheme in the real world – for example, for the 100 000 trees project, the existing user group from the physical planning scheme was utilized in the study of XR for that same task. The data collection protocol was then designed using various methods from user interaction such as observation, screen recording, interviews that were conducted as similar as possible across cases to understand users' interactions and experiences with XR.

Cases

Case study 1 - Case Study of the Design of the 2022 Nordic Pavilion Exhibition at the Venice Biennale.

The first case study documents the design process of the physical and digital versions of the heritage-valued Nordic pavilion at the Venice Biennale. The case facilitated a multiuser collab-

Figure 2 and 3. Left: Conducting design review in MR inside a studio from case study 1 Right: Youth participant places trees on site through AR in case study 2

Figure 4 and 5. Left: Local participant from participatory planning workshop in Mauritz Hansens gate explains their proposal through the AR application in Case study 3. Right: Figure 5 The participants were surveyed on their cognitive-emotional response to the wall types through interviews, go-along interviews while inside VR, and through screen-recorded observation in case study 4.

oration in mixed reality (MR), studying the technologies' influence upon user interactions and design decision making. The case study documents how artworks and positions of artworks were tested in various configurations within the MR model by curators and designers to simulate the spatial experience of the design options. Several key design decisions were made based on the unique vantage points offered in MR. The MR model was then used to generate 2D technical documentation and installation instructions, which were installed on site.

Case study 2 - Augmented reality as a participation tool for youth in urban planning processes: Case study of the 100 000 new trees project in Oslo, Norway.

The second case study consists of field work with AR between 2020 and 2021 over five weeks, with five different groups of youth participants from eight different districts of Oslo, who were tasked with planning a portion of Oslo's 100,000 new trees.

Case study 3 - Utilizing XR in the participatory planning of a car-free street; Case study of Oslo, Norway and the 'Living Streets' project.

For this third case study, we partnered with Oslo Municipality and the City District Administration of Frogner in conducting

Table 1. Case studies in cross-case analysis; technology domain, user group, methods, and case study report publication type

Case no	Title	Technology	User group	Methods	Case study report, Publication, year
1	**Mixed Reality in Multiuser Participatory Design: Case Study of the Design of the 2022 Nordic Pavilion Exhibition at the Venice Biennale**	3d scanning, VR, Oculus Quest 2, HTC Vive, Arkio	(Sami) artists and curators	Observation, Screen recording, Interviews	Buildings (MDPI), 2022
2	**Augmented reality as a participation tool for youth in urban planning processes: Case study of the 100 000 new trees project in Oslo, Norway**	AR, iPad Pro, iScape	Local youth	Observation, Screen recording, Interviews	Frontiers of Virtual Reality, Augmented Reality Special Issue, 2023
3	**Utilizing XR in the participatory planning of a car-free street; Case study of Oslo, Norway and the 'Living Streets' project**	AR, iPad Pro, iScape, Augment	Local adults and youth	Observation, Screen recording, Interviews	Repurposing Places for Social and Environmental Resilience. 2023 Proceedings
4	**Evaluating the user experience of architectural archetypes through XR**	VR, Arkio	Youth	Observation, Screen recording, Interviews	The International Association for the Study of

participatory planning for the Living Streets project, specifically the street of Mauritz Hansens gate, which is undergoing planning approval for conversion from a car street to a car-free 'Living Street'.

Case study 4 - What is the role of architectural history and theory in the future? Evaluating the human experience of architectural 'archetypes' in virtual reality (VR)

The goal of this fourth case study was to evaluate whether implied experiential qualities in architecture were experientially transferable through to a virtual environment. Therefore, the research team studied the seminal literature in Evensen (1987) Archetypes in Architecture and modeled full-scale replicas of the 8 wall archetypes in the publication within a virtual environment.

Findings

Our findings are developed in the form of individual case study reports, submitted to peer-review, and published as individual cases in the corresponding journals. Through utilizing the Yin (2013) diagram we then form cross-case conclusions in this text. Across cases, we found that XR influenced the user experience and decision-making processes in each case in a variety of different ways. In general, XR is particularly useful when conducting field work that allows users to see and create designs and interact with proposals, creating a form of qualitative user data that can be directly integrated into the final design. This allowed users to create their own designs in situ and to present their designs to an audience, leading also to those designs being directly implemented into the future built result (Reaver, 2022; Reaver, 2023). Further, our findings depicted a high degree of transferability between the XR models and the physical results, suggesting that there is some transferability between the spatial experience of XR over to the real world at a cognitive level.

There are several differences between AR and VR which are worth noting. While it is claimed that digitization can help planners make more informed decisions and improve the quality of their designs and to support decision-making in real-world settings (Hasler et al, 2017), we find that the nuances between the technology domains are important to articulate and develop rather than pushing a general notion of digitization regardless of technology choice. For example, we found that Virtual reality (VR) is more useful for precise spatial studies in high detail, such as in construction and in heritage work (Reaver, 2019), but is also a specific type of technology with relatively high costs involved (Reaver 2022). This type of technology appears useful in performing pre-occupancy studies with users before construction, planning exhibitions, changes to existing buildings, and other similar types of use at interior or building scale. In extension of this argument, we found that AR is a highly intuitive tool for users in design and planning in urban settings, and we found that the use of AR impacted final design outcomes. The use of AR aided users' ability to generate their own planning proposals on site at scale, and in addition, users experienced an increased sense of confidence in displaying their design intentions and appreciated being given control of the planning process.

Some of our more notable findings concern the use of a technology like XR in an environment in which most of the development in conducted by private technology companies, creating difficulties in preserving user privacy, understanding black boxes, and generating secure and viable user data. We notably had to create fake user accounts in order to protect user privacy in accordance to research ethics standards, which also created difficulties with the Terms of Services (TOS) with the XR tools. Silverman and Cambell (2021) have noted that while we historically have let societal, judicial, and legislative forces produce rules for new technologies, XR is outpacing this watch-and-wait approach. For example, some proponents of regulation argue that XR technology has the potential to be misused or abused in ways that could harm individuals or society, and that regulations are necessary to prevent these harms from occurring.

Conclusion

It is important to reiterate that the studies were chosen to study how XR influenced normal everyday users in typical planning and design contexts. Here, it has been claimed that digital technologies can be used to engage the public in the urban planning process by making complex planning concepts more accessible to the public (Saner et al., 2019). The cross-case analysis allowed us to study this notion in some detail. The data from the cases suggests the involved users found the XR tools to be a productive medium in understanding design proposals, proposing their own designs, and in influencing final design outcomes. This aspect of the studies was shown to influence the decision-making of the responsible authorities in the planning process, perhaps showing how digitization and XR can influence co-design and participatory design by creating new forms of qualitative user data.

One could argue that the use of XR in the design and planning of the built environment seems to follow trends in technology development and design methodology towards the integration of user into the design process more in general. Here, we believe that XR could be one of several tools and should not be viewed as the only way in which to increase qualitative user data in the design and planning of the built environment. As we have shown some of the technical and regulatory difficulties regarding XR today, we believe there is a strong need for the to develop conceptual and methodology ideas for understanding virtual and non-virtual environments in a more holistic and empirically grounded manner than current practice before recommending any further expansion of the technology. It also seems critical that regulators and public institutions are afforded more insight and control over the development of XR if it is to be used for such types of use involving everyday citizens. Here, we think that some of the interesting work being conducted at the intersection of human cognition, embodiment within space, and the phenomenological experience of space such as Pykett et. al (2020), Naghibi et al., (2023), and many others have demonstrated, could help move such research forward.

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