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EMPIRICAL RESEARCH

E-participation and the Metaverse – insights from a Design Science Research project on immersive public participation

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ABSTRACT
Low levels of public participation in local decision-making, particularly in urban planning, remain a persistent challenge. While e-participation offers new avenues for engagement, achieving broad-based and inclusive participation remains difficult, especially given the complexity of construction plans. This paper addresses this issue by exploring how xReality (XR) technologies can enhance e-participation in urban planning. Using a Design Science Research (DSR) approach, we derive meta-requirements and design principles for inclusive XR-based e-participation. Across three design cycles and three empirical studies, we develop and evaluate a participatory XR artifact. As cities increasingly adopt digital twins, XR emerges as a promising tool to enhance citizens' understanding of urban projects through intuitive, interactive visualizations. These representations help bridge cognitive gaps and foster greater motivation to engage. However, participation is not monolithic, as citizens differ in the degree of influence they seek, ranging from merely being informed to actively participating in decision-making. Our design theory emphasizes support for these varying levels of participation. The study provides insights into developing inclusive e-participation tools and highlights key expectations from both citizens and public-sector stakeholders. Ultimately, we show how XR can support more equitable and effective e-participation in the Metaverse.

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Metaverse; e-participation; augmented reality; virtual reality; digital government; Design Science Research; digital democracy

1. Introduction

E-participation has become a central instrument for enabling citizen involvement in public decision-making, particularly at the local level, where planning decisions directly affect citizens' everyday environments (Taylor et al., 2020). E-participation emerged with the promise of making public participation more inclusive by enabling participation independent of time and place (Macintosh, 2004)—thereby empowering individuals who are unable to attend in person due to caregiving responsibilities, disabilities, or mobility limitations. Yet public decision-making processes are often complex and difficult for citizens to comprehend, creating barriers for broad audiences.

Across contexts such as participatory budgeting, environmental consultations, or policy co-creation initiatives, these barriers result from persistent socio-technical challenges in e-participation. Citizens are expected to engage with complex information, understand procedural constraints and decision-making logics, and articulate contributions whose impact often remains opaque. Addressing these challenges is essential for achieving inclusive citizen engagement. Prior research shows that platform design significantly shapes engagement patterns (Zheng, 2017). Hence, the question is not whether design matters, but how e-participation systems should be designed to address these structural challenges.

Immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR)—increasingly discussed and framed in the context of the Metaverse (Dolata & Schwabe, 2023)—offer potential remedies to these challenges. By enabling spatially situated, interactive, and embodied experiences, immersive systems can enhance the understanding of complex participation scenarios, especially for non-experts. Previous work in domains such as medical training and engineering has shown that XR can improve comprehension and engagement (Goudarznia et al., 2017; Lorenz et al., 2016; Wolf et al., 2020). Moreover, XR has shown potential for inclusive design, for instance, by facilitating access for people with physical impairments (Gerling et al., 2020) or by supporting self-organizing marginalized groups in social VR contexts (L. Li et al., 2023).

We use urban planning as an analytically rich empirical setting in which the generic e-participation challenges appear in particularly pronounced form and for which XR technology might be a particularly well-suited e-participation solution. Urban planning combines abstract decision-making with spatial complexity and highly technical, expert-driven forms of representation such as architectural maps and con-

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struction schematics, which require considerable spatial perception capabilities and familiarity with professional conventions (Brettschneider, 2013).

E-participation tools often struggle to replicate the embodied experience and spatial comprehension provided by on-site formats (Stein & Fegert, 2024; Stein et al., 2025; Wolf et al., 2020), which further amplifies the information-load and comprehension barriers characteristic of e-participation more generally. Urban planning decisions are additionally shaped by tightly coupled procedural constraints, including material and structural dependencies (e.g., load-bearing limits, static requirements), regulatory approval procedures, and budgetary cycles, which further complicate the comprehensibility of planning trade-offs for non-expert audiences. Finally, uncertain impact of own contributions are likewise pronounced in this setting: multi-year planning horizons make it difficult for participants to locate the present moment within the larger trajectory, standard visual formats such as site plans and construction schematics depict spatial outcomes but not the procedural sequence in which citizen input enters the decision pipeline, and planning trade-offs are typically negotiated across multiple administrative levels, so that the actual weight of contributions often remains unclear.

Against this background, this paper explores how immersive systems can be designed to support inclusive e-participation while lowering participation barriers in urban planning processes. The growing use of digital twins in cities (Caldarelli et al., 2023) suggests that immersive participation may soon become an integral component of public planning processes. Yet, to date, the integration of XR into e-participation has mainly focused on technical feasibility (e.g., CAD model integration), often neglecting critical issues related to reducing barriers and sustaining engagement (Simonofski et al., 2024; Wolf et al., 2020).

In this paper, we conceptualize inclusion as enabling citizens to participate as equals by lowering barriers that prevent meaningful participation, drawing on Nancy Fraser's notion of participatory parity (Fraser, 2014) and deliberative democratic theory's emphasis on equal opportunities to participate in public reasoning (Habermas, 1981). In the context of immersive systems in e-participation, we operationalize inclusion primarily as barrier reduction for broad audiences, focusing on cognitive, procedural, and interactional thresholds (e.g., orientation, comprehensibility, and confidence to contribute). Importantly, our evaluation does not provide systematic evidence for specific underserved groups; we therefore restrict inclusion-related claims to barrier reductions evidenced in our data. In this paper, we distinguish inclusion (barrier reduction enabling participatory parity) from engagement (sustained motivation to participate) and from participation intensity (participation levels).

To address the lack of empirically grounded design knowledge on how immersive technologies can lower participation barriers and support differentiated levels of engagement in e-participation, we present a Design Science Research (DSR) project that develops and evaluates an XR-based e-participation artifact. As the empirical setting for the artifact development, we draw on a real-world urban planning case—the redesign of a publicly owned green space in a German city—in which the e-participation challenges appear in particularly tangible form. The artifact supports different levels of citizen engagement by aligning specific functionalities with the five-level Spectrum of Public Participation (SPP) framework (2018). We use this framework as a kernel theory to guide the design process, enabling a structured response to varying expectations and capacities for e-participation from informing to empowering. Accordingly, the design goal of this study is to develop and refine meta-requirements (MRs) and design principles (DPs) for XR-based e-participation that enable inclusive and motivating involvement in e-participation processes. Based on this goal, we explore the following research question:

RQ: How should an XR-based e-participation application be designed to enable public participation in urban planning?

Using a DSR approach (Ar et al., 2004), we present an XR-based e-participation artifact through three cycles of the DSR in Information Systems (DSRIS) framework, setting MRs and DPs for immersive e-participation systems. In the first DSRIS cycle, stakeholders' needs for XR-based e-participation were identified qualitatively ($n = 27$). The second cycle refined findings quantitatively ($n = 339$), as the prototype was further developed and evaluated with a focus on differentiating between AR and VR environments. The final cycle involved a quantitative evaluation ($n = 382$). For the three studies, we collaborated with the administration of the German city of Karlsruhe on a real-world use case, involving e-participation in redesigning a publicly owned green space belonging to the city-owned zoo.

Based on these studies, we derive a set of MRs and DPs that contribute to both theory and practice. While the artifact is tailored to participatory urban planning, the resulting design knowledge addresses general challenges in developing XR-based e-participation systems, insofar as such systems confront citizens with complex information, procedural uncertainty, and varying capacities for engagement—challenges that are particularly pronounced in urban planning but not limited to it. In particular, we contribute a transferable design logic that can be adapted to other domains where barrier reduction in public decision-making is desired. This design logic is exemplified, for instance, by aligning functionalities and navigation with the stages of the SPP framework to guide users transparently through different levels of participation. However, we recognize that our design artifact and the resulting design knowledge represent just a small step toward reducing barriers to engaging with e-participation applications. Much more effort is needed to engage and motivate a diverse society effectively.

In sum, this paper responds to the call of Weinhardt et al. (2024) to develop innovative concepts for digital involvement and to establish design principles for resilient digital democracies. The United Nations (UN DESA, 2022) emphasize that local governments must integrate residents' perspectives, not only in service provision but also in decision-making. E-participation plays a key role in achieving sustainable development goals by fostering citizen-centric, collaborative decision-making without requiring binding commitments (Pfeiffer et al., 2021). By leveraging XR, our research contributes to this debate, exploring its potential to enhance participatory processes and lowering participation barriers.

2. Related work

2.1. Public participation and e-participation

Active citizenship is theoretically built on the concept that effective communication between civil society and politics is essential for representative democratic decision-making (Habermas, 1992). Public participation and e-participation are rooted in this theoretical foundation, often drawing on deliberate models that prioritize rational, inclusive discourse. In particular, Habermas's concept of the public sphere has been influential in shaping theories of participatory systems design (Haj-Bolouri et al., 2016; Sanford & Rose, 2007). However, scholars like Nancy Fraser (Fraser, 1990) have highlighted the limitations of this ideal by pointing to the historical exclusion of marginalized groups (e.g., women, ethnic and religious minorities, low-income populations, or people with disabilities) from public discourse. Fraser introduces the concept of "subaltern counterpublics" to emphasize the need for alternative discursive spaces where underrepresented voices can develop and gain strength before entering dominant deliberative arenas. Central to her theory is the principle of participatory parity and the idea that democratic justice requires institutional conditions that enable all individuals to participate as equals, regardless of their social or cultural status. In the context of e-participation, this perspective is particularly important: unless participatory systems are deliberately designed to lower participation barriers, accommodate diverse abilities, backgrounds, and communicative practices, they risk reinforcing rather than reducing existing inequalities.

In 1996, political scientist John S. Dryzek stated, "If democracy is a good thing [. . .], then more democracy should presumably be an even better thing" (Dryzek, 1996). The concept of participatory democracy, as revisited by Pateman (2012), highlights the increasing emphasis on citizen participation beyond mere representation, aligning with broader trends in democratic theory. Today, public participation seems crucial in representative democracies, ensuring citizens' voices are heard and empowering them in decision-making (Taylor et al., 2020). Several definitions of public participation exist that differentiate between different forms of citizen participation: Arnstein's (1969) Ladder of Citizen Participation conceptualizes eight hierarchical levels, framing participation as a function of power and exposing the manipulative potential of tokenistic forms of engagement. A more recent contribution to defining forms of participation is the SPP developed by the International Association for Public Participation (2018). The SPP focuses on different levels of participation that have varying impacts on decision-making (see Figure 1). The levels range from "inform" (provide information to help the public grasp the issue and its solutions), and "consult" (gather public input on alternatives and decisions) to "involve", (work with the public throughout the process to ensure their concerns are considered) "collaborate", (partner with the public on all aspects of the decision, from alternatives to the preferred solution) and "empower" (place decision-making authority in the hands of the public). This framework is widely used, considered to be objective, measurable (Nabatchi, 2012; Nelimarkka et al., 2014), and suitable for participation processes involving multiple stakeholders (Wirtz et al., 2018). Voting is the first

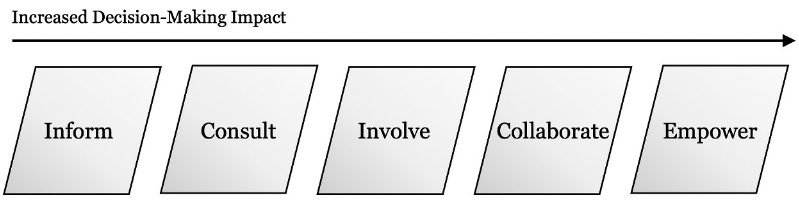


Figure 1. Brief overview of the five levels of the spectrum of public participation (2018).

association people might have with participation. As the spectrum shows, final decision-making could be a dimension of participation processes. However, it is essential to recognize that other dimensions, such as informing the public, can, if pursued with democratic intentions, also be an important means of public involvement. Thereby, the framework enables conceptualizing participation beyond a rigid hierarchical framework: every step on the participation ladder may be a valuable part of citizen participation. Nevertheless, the SPPs' differentiation is significant for a precise understanding of public participation and for identifying appropriate procedures (Stein et al., 2023).

We believe that differentiating between various forms of participation is crucial to assessing the suitability of specific technological innovations for participation procedures. Therefore, we utilize the spectrum in our studies to better understand these distinctions, also when employing immersive technologies in e-participation.

In general, e-participation is a sub-branch of e-democracy, a form of digital government. Following the idea of digital government (Falk et al., 2017), governing processes should be transformed for the digital age not only by replicating and digitizing established procedures, but also by leveraging new digital opportunities. While digital government is the broad term to describe interactions between the citizen and it's governing body through the use of ICT (information and communications technology), Macintosh, in accordance with Sæbø et al. (2008), defines e-Democracy as "the use of ICT to support the democratic decision-making processes" (Macintosh, 2004, p. 1) and thereby helping to implement the steps of the spectrum of public participation. With reference to Falk et al. (2017), the aim here should not be solely to transfer analog processes to the digital domain, but also to consider how these processes can be better designed or enriched with technology. Ensuring inclusion in participation processes remains a persistent challenge with public participation. Research has shown that while gender disparities may not be evident, age-related differences influence engagement, with younger and older citizens participating less actively (Van Den Berg et al., 2020). Furthermore, participant recruitment strategies shape participation outcomes, suggesting that inclusion depends not only on platform accessibility but also on targeted outreach and advertisement strategies. Another key challenge is technological hesitancy, as e-participation platforms are predominantly browser-based and optimized for desktop use, limiting accessibility and reinforcing non-inclusive participation patterns (Rottinghaus & Escher, 2020). Additionally, accessibility concerns extend beyond hardware compatibility, as platform design influences usability and engagement, particularly for individuals with lower digital literacy (Santos Gonçalves et al., 2021). To address these challenges, our study adopts a DSR approach, incorporating user-centered design principles to ensure that participation platforms reflect the needs of diverse user groups to lower participation barriers. By integrating mobile-first strategies, intuitive XR interfaces, and diverse stakeholder involvement, we explore how technological innovations can enhance e-participation. Our focus on inclusion is therefore conceptualized as the reduction of cognitive, procedural, and interactional barriers that hinder meaningful participation.

In line with this, research in information systems has made valuable contributions to understanding and advancing e-participation. However, the e-participation's interdisciplinary nature also poses challenges, particularly in structuring accumulated knowledge and developing unified frameworks for analysis and design (Santamaría-Philco et al., 2019). Mcgrath et al. (2012) highlight both the democratic potential and institutional limitations of online social networks in fostering public participation, emphasizing the need for inclusive participation environments. Becker et al. (2022) advocate for citizen-initiated, ICT-supported participation in smart cities. Recent design-oriented work explores how political information systems can actively foster societal discourse, for example, by using video technologies to encourage dialogue between opposing groups (Benke et al., 2025). Empirical findings further show that while external shocks such as COVID-19 may accelerate e-participation, they do not automatically lead to more inclusive engagement (Büll & Fegert, 2025; Roztocki et al., 2023). A systematic review by Leible et al. (2022a) reinforces this insight, demonstrating that the type of ICT used influences the inclusivity and equality of e-participation. Taken together, these studies underscore the importance of context-sensitive, IS-informed design approaches, yet few solutions have been offered. Our XR-based artifact tries to close this gap by providing concrete design knowledge on how immersive technologies can support more inclusive and engaging forms of e-participation.

Within the IS literature, the term inclusion has been mobilized in two distinct, though related, ways. A first body of work examines digital inclusion and digital inequality, focusing on disparities in access, skills, and continued use of digital systems and their consequences for participation in digitally mediated public life (Agarwal et al., 2009; Jjp-A et al., 2011). A second body of work, recently consolidated in special issues and research roadmaps, frames social inclusion/exclusion in IS more broadly, asking how digital systems contribute to or hinder the meaningful participation of marginalized groups across societal contexts (In et al., 2025; E. Trauth, 2017; E. Trauth et al., 2018). Both are concerned with barrier reduction, but they typically focus on barriers at the access, skill, infrastructure, or group-level participation levels. In IS research on e-government and e-participation specifically, this has translated into work on platform accessibility, recruitment, and the differential uptake of online participation formats (Leible et al., 2022b; Van Den Berg et al., 2020).

While digital inclusion centers on access to digital infrastructure and social inclusion focusses on the participation outcomes of specific underserved groups, our approach shares the broader normative concern of the latter but pursues it through a different design strategy: rather than designing for specific groups, we target system properties such as orientation, comprehensibility, and confidence to contribute, which are intended to lower participation barriers for broad audiences and which we expect to benefit, in particular, those groups whose participation has previously been constrained.

Building on Fraser's (2014) notion of participatory parity and on deliberative democratic theory (Habermas, 1981), we conceptualize inclusion as enabling citizens to engage as equals in public reasoning, with a specific focus on the cognitive, procedural, and interactional barriers that prevent meaningful participation in immersive e-participation environments. What our XR-based artifact addresses, and what our empirical evaluation supports, are therefore not access or skill barriers at the level of digital infrastructure, but barriers that arise once digital access and basic interface skills are in principle given: barriers of orientation, comprehensibility, and confidence to contribute. We accordingly restrict inclusion-related claims in this paper to such barrier reductions and do not extend them to systematic effects on specific underserved groups, which would require dedicated subgroup designs (see Limitations).

2.2. The Metaverse and XR

In the 1990s, Lombard and Ditton found that telepresence and immersion led to higher "participation" and a "sense of involvement" (Lombard & Ditton, 1997). We keep these early findings in mind when suggesting the combination of e-participation and immersive systems. We begin by defining the Metaverse and XR, then elaborate on the differences between AR and VR, and reflect on key aspects of immersive systems relevant to this research.

The Metaverse is a hypothetical, immersive virtual space that represents the next generation of the Internet (Dwivedi et al., 2022; Xi et al., 2023). Currently, multiple virtual environments exist, organized by different platform providers, containing various virtual objects and accessible from multiple devices. The Metaverse aims to create a seamless digital world that blurs the lines between reality and virtuality, enabling new forms of social interaction, commerce, and entertainment (Dwivedi et al., 2022). XR encompasses all immersive technologies that enhance human perception of reality, including AR, VR, and mixed reality (Xi et al., 2023). We acknowledge that Rauschnabel et al. (2022) criticize the XR umbrella's blurriness and propose xReality as a replacement term, where X can be replaced by either A (as in AR) or V (as in VR). In this paper, because of its popularity, we use XR as an umbrella term and highlight the differences between AR and VR. While XR adoption is supported by technological advancements and new actors, such as Apple, its relevance in our context lies in its potential to address practical barriers to e-participation, including the abstractness of planning data, low user motivation, and accessibility issues.

AR gained mass market popularity in the 2010s (Rauschnabel Pa, 2021). Its first practical application was defined by Azuma 1997) as a 3D real-time visualization uniting physical surroundings with virtual elements. In many fields, AR has established itself as beneficial: AR product presentations are better evaluated than traditional web-based ones due to their vividness and interactivity (Barta et al., 2023; My-C et al., 2017), and studies in urban planning demonstrated its potential to make construction information more graspable for non-experts (Rockmann et al., 2015). Boos et al. (Boos et al., 2023) further support this view by showing that AR applications enable users to better envision planned urban structures than traditional methods, such as construction spans, especially when detailed façade elements are integrated to aid spatial estimation. This benefit of enhanced comprehension is also reflected in literature highlighting the importance of visualizing 3D data for urban planning, as it assists understanding (Devaux et al., 2018; Fonseca et al., 2014). Graspable visualizations enhance visuospatial thinking and cognitive processing (Drettakis et al., 2007). These findings are particularly relevant to e-participation in urban and spatial planning, where understanding complex planning proposals is often a barrier to meaningful engagement.

VR, in contrast, is defined as a "computer-generated, interactive, 3D environment in which people become immersed" (Wexelblat, 1995; also; SuhK-S & Lee, 2005). Head-mounted displays (HMDs) are the most popular way to access VR (Weiss & Pfeiffer, 2024). VR increases motivation and interest, making it useful for visualizing construction projects (Barnes, 2016; SuhK-S & Lee, 2005; Whyte, 2003). VR has proven effective in education and knowledge acquisition (Bilge et al., 2016; Jiang et al., 2018; Stejskal et al., 2023; Van Leeuwen et al., 2018). For e-participation, VR's motivational pull and its capacity to foster spatial presence offer pathways to counteract citizens' lack of confidence in their own knowledge—a barrier to engaging in participatory formats (Zheng, 2017).

Additionally, research has demonstrated its potential to enhance inclusion by addressing accessibility barriers, as Zhang et al. (2025) show in their study on immersive VR for disability inclusion. Their findings highlight how well-designed immersive environments can empower diverse user groups.

Both technologies also have downsides for urban planning: VR users may struggle with real-world dimension estimation (Rokhsaritalemi et al., 2020), while AR embeds objects in the real world but offers lower immersion. Therefore, combining both technologies in e-participation can offer a seamless transition from 2D to immersive 3D environments. This approach allows off-site participation, crucial for asynchronous participation. Following Nuernberger et al. (2016), we enhance mobile participation by adding additional content such as text, pictures, and audio. Affordable hardware and software now enable remote participation in construction projects and urban planning (Wolf et al., 2020). Extending these perspectives, Hy et al. (2024) highlight human-centric design as key to the Metaverse's future, suggesting that brain-computer interfaces could enable more intuitive interaction.

In sum, immersive technologies offer affordances—such as vivid visualizations, spatial understanding, and heightened user engagement—that align with persistent challenges in e-participation.

3. Method

3.1. DSRIS framework and genres of inquiry

In our paper, we rely on the DSRIS framework by Kuechler and Vaishnavi (2008), which is based on Ar et al. (2004) and follows the three-cycle-view offered by Hevner (2007).

According to Peffers et al. (2007), demonstrating an artifact is also a critical step toward solving instances of the problem and thereby showing its utility (see Figure 2 for an overview of our activities). In our project, we conducted such demonstrations, understood as proof-of-concept activities, at multiple points and in various stakeholder contexts. Many of these demonstration activities were integrated into more formal, measurable evaluation processes, which will be described in detail in the following sections. Other demonstration activities focused solely on showcasing the artifact and included four workshops and meetings with the zoo and city administration, in which we presented prototypes from different design cycles. We also conducted an on-site demonstration of the app in the publicly-owned zoo green space, where it was tested and observed by passing visitors in a real-world setting. These demonstrations helped validate both the usability and contextual relevance of the artifact in situ.

As part of the DSRIS framework, we incorporate different genres of inquiry to enhance the knowledge production process of this paper. According to Baskerville et al. (2015), inquiry genres can be categorized into idiographic and nomothetic designs, as well as into science and non-science. In Study I, we follow an idiographic design approach, using a qualitative expert interview approach for the concept evaluation, focusing on generating knowledge specifically applicable to our unique problem setting and the artifact development. The study provides insights from the specific context, contributing to the refinement and validation of our design through the instantiation of an early prototype tailored to the stakeholders' specific

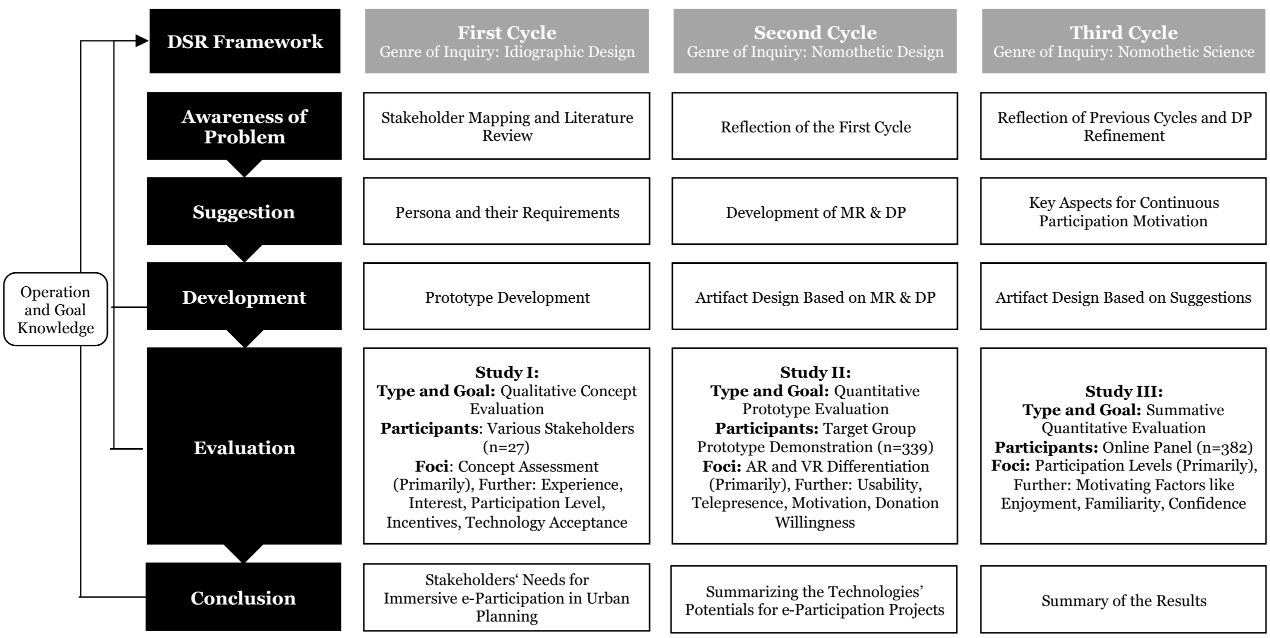


Figure 2. Overview of activities across the three DSRIS cycles (following Kuechler & Vaishnavi, 2008; Hevner, 2007.

needs (see Figure 2). Study II, on the other hand, uses a quantitative field evaluation and a nomothetic design approach, producing knowledge that is more generalizable and applicable to a broader range of problems. This approach enables us to derive general design principles and theories that extend beyond the immediate case, offering valuable insights that could be applied to similar contexts. Lastly, in Study III, we employ a nomothetic science approach, aiming to develop generalizable knowledge and theories about the interaction between our artifact and various social settings, specifically the different SPP levels. This approach allows us to rigorously test and validate the artifact's effectiveness across different e-participation settings. For this summative evaluation, we conducted a quantitative online study, testing its reliability and external validity (see Figure 2). By combining these different genres of inquiry, our research not only contributes to the development of a specific e-participation artifact but also generates broader theoretical insights that enhance the understanding of how immersive systems can be effectively utilized for e-participation. The five-level SPP will serve as a "kernel theory" for our DSR. As such, it is the underlying knowledge, in our case from social science, that gives a basis and explanation for the design (Gregor & Jones, 2007). We use it as justificatory knowledge that guides the main structure of the resulting artifact: The artifact supports all the different levels of the spectrum of participation with specific functions and processes to enable users to engage at their preferred level of decision-making impact.

3.2. Applying SPP as Kernel theory across the design process

While the SPP provides the overarching justificatory frame, its role in the design process varied across the three DSRIS cycles. We make this differentiated use explicit here, as it determines how meta-requirements and design principles were derived rather than imposed.

In the first cycle, the SPP entered the design process as an interpretive lens rather than a prescriptive grid. The stakeholder mapping and the qualitative interview guide were structured around general e-participation dimensions (experience, degree of participation, incentives, and technology acceptance), but the SPP framed how participants' statements about their willingness and capacity to participate were coded. This allowed us to identify level-specific challenges, for example, that respondents articulated lower self-perceived competence and stronger demand for guidance at higher participation levels, without forcing a one-to-one mapping between SPP-levels and challenges. In terms of Möller et al. (2022), this corresponds to analyzing data with a theoretical lens (Mechanism 2).

In the second cycle, the SPP was again applied as a theoretical lens to the qualitative material (analyze with lens; Möller et al., 2022, Mechanism 2), now with a different analytical purpose: while Cycle 1 used the SPP-as-lens to identify level-specific challenges, Cycle 2 used the SPP-as-lens to derive prescriptive meta-requirements from those challenges. We systematically reviewed the challenges identified in the qualitative material for each SPP level and asked which design-relevant requirement would need to be met for participation at that level to be possible for non-expert audiences. The result is summarized in Table 2. Because several challenges proved relevant across multiple SPP levels, the mapping is not strictly one-to-one, producing a layered structure in which lower-level requirements (e.g., access) remain preconditions for higher-level engagement.

In the third cycle, the SPP was applied through two further Möller mechanisms, both targeting the design principles. First, the SPP served as a refinement lens (refine with; Möller et al., 2022, Mechanism 4): each DP was reformulated to specify which SPP levels it primarily addresses (see Kernel-Theory-Based SPP-Mapping in Table 4) and to articulate the mechanism by which it supports participation at those levels. This made participation depth a configurable design dimension rather than an implicit backdrop. Second, the SPP served as an evaluation lens (evaluate through; Möller et al., 2022, Mechanism 6): the summative quantitative study in Study III assessed whether the experiential effects implied by the DPs (enjoyment, familiarity, confidence) systematically varied across the five SPP levels.

Through this differentiated use, SPP guided the design process at four distinct points across the Möller mechanisms: as an analytical lens in Cycle 1 (for identifying level-specific challenges) and in Cycle 2 (for deriving meta-requirements; analyze with lens, Mechanism 2 in both cases), as a refinement lens for DP reformulation in Cycle 3 (refine with, Mechanism 4), and as an evaluation lens for the summative empirical assessment in Study III (evaluate through, Mechanism 6).

4. Designing an XR-based e-participation application

As shown in Figure 2, we adopted a DSR approach comprising three cycles, which will be explained in detail in the following sections. Afterwards, the paper concludes with a qualitative study that contextualizes these DSRIS findings within the Metaverse.

4.1. First cycle

4.1.1. Problem awareness: problematization of the application case

We began the first cycle by exploring the needs and challenges for an XR-based e-participation application through a literature review on different forms of e-participation projects (Fegert 2022), presented briefly in the foundations chapter. A lack of focus on inclusion and the participation process itself became visible through this literature review. Integrating the SPP into the e-participation research process could help to ensure the artifacts' transferability to other contexts. Furthermore, we conducted a comprehensive market analysis based on twelve e-participation platforms (Fegert 2022), which revealed a significant gap: there is currently no commercial platform that utilizes immersive systems. This finding underscores the lag in XR adoption in e-participation compared to other sectors, such as gaming and e-commerce. We therefore aimed to develop design knowledge using a concrete application case for which we could develop such an immersive system.

4.1.1.1. Application case. The publicly owned zoological garden of the city of Karlsruhe planned the creation of a new island within its recreational park, designed as a freely walkable enclosure for lemurs and fully accessible to zoo visitors via bridges. Although the zoo is a public institution financed and controlled by the city, the project was realized as a public–private partnership, funded in part through private donations coordinated by a "Friends of" charity organization. The redesign of the island represents an architectural novelty for the zoo, motivating its management to actively involve citizens in the planning process. Many aspects of the island's design remained open for discussion, making the project particularly suitable for our research purposes. In addition, the strong relationship between the citizens of Karlsuhe and the recreational park increased the likelihood of public engagement. Given the expectation that immersive visualizations could make planning decisions more tangible, the institution expressed a specific interest in testing an AR- and VR-based e-participation application in this context. As is typical for large public construction projects, the resulting infrastructure is used by a highly heterogeneous population and involves multiple stakeholders with diverse interests (Thy et al., 2013).

This application context surfaced a set of situated, interdependent design problems that could not be adequately addressed by upfront requirements specification or ex post evaluation alone. As a publicly accessible urban space, the zoo engages a highly heterogeneous user population with diverse ages, prior knowledge, digital skills, and participation motives, creating challenges for enabling meaningful e-participation beyond self-selected or expert publics.

At the same time, the planning project required communicating complex spatial, ecological, and financial constraints to non-expert audiences while complying with the data protection and governance requirements of a publicly funded institution. These conditions rendered the design problem ill-structured and context-dependent, with key requirements only emerging through iterative artifact instantiation and use. Consequently, a DSR approach was adopted to derive meta-requirements and design principles through cycles of problem–solution co-articulation grounded in empirical engagement.

4.1.2. Suggestion: personas and their requirements

Design knowledge development: In a workshop with e-participation project initiators, we clarified the use case's aim and scope: offering citizens the opportunity to actively participate in the zoological garden's construction project and gain insights into the accessibility of the planned island. Afterwards, a stakeholder mapping workshop (Axelsson et al., 2013) identified stakeholders' perspectives and potential conflicts, involving representatives from relevant groups, and found stakeholders on the initiators, beneficiary, and supply sides. We created detailed personas (Sinha, 2003) reflecting diverse characteristics to understand potential users' needs, goals, and preferences, such as a grandmother, her grandchild, a teacher, zoo staff, a local government representative, and an XR expert. Combining these personas with the literature review, we developed tentative requirements. Those revealed that the main challenge is to motivate citizens and to create an easy-to-use application, given the lack of familiarity with XR. Furthermore, integrating cutting-edge technologies and prioritizing interoperability will be key to advancing e-participation and making it more engaging and inclusive. The personas also showed that the question of the level of participation, based on the SPP, could be answered differently depending on the persona's background and function. Thus, in the first evaluation round, we focused on a prototype that would enable citizens to imagine what an immersive e-participation application might look like, thereby deriving meta-requirements.

4.1.3. Development: first two prototypes in AR and VR

The development of the XR e-participation artifact is part of a collaborative research project involving scientists of research institutions as well as three tech companies: Raumtänzer GmbH, a research-oriented company specializing in AR and VR applications, Neuland-Medien GmbH, a media agency, and CAS Software AG, a company for CRM software whose working packages are not part of this study.

Raumtänzer GmbH and CAS Software AG, which we will refer to as the development team, contributed to the implementation and parts of the creative design process.

4.1.3.1. Feature evolution. To develop meta-requirements important to both AR and VR applications and to provide insights into the necessity of interoperability between these two environments, we developed two prototypes. The initial prototype (Figure 3) utilized a postcard featuring the construction site, along with a conventional smartphone equipped with a preinstalled AR application developed specifically for this use case. Nevertheless, the visualizations were kept comparatively simple and focused more on a basic demonstration of the idea. The used smartphone's camera identified markers printed on the postcard (a common practice for advertising agencies to illustrate an AR application), allowing virtual elements to be displayed on the device, representing a version of the construction site. Furthermore, a VR version was created using an HMD, presenting a simple 3D model of the construction site. It is compatible with smartphones, tablets, and HMDs, and can be controlled through lifting, lowering, and turning the mobile device. In the case of HMDs, navigation can be done using controllers.

The system development team utilized the provisional requirements to develop the application, which was later evaluated by the various stakeholder groups and iteratively refined.

4.1.4. Evaluation: qualitative study and its results

In line with the development process, we designed a qualitative study to explore the various motivations and requirements (Fegert et al., 2020). Axelsson et al. (2010) and Holgersson et al. (2018) demonstrated the importance of citizen participation in e-government projects, and we want to respond to this call by bringing citizens' insights into the design process early on. Through an exploratory approach, we also aim to draw attention to new phenomena (E. M. Trauth, 2001). An overview of DSR cases, edited by vom Brocke et al. (2020), demonstrated the high relevance of qualitative interviews in DSR but also highlighted the vagueness of their conduct. Therefore, seeking a suitable method, we decided to follow Kaiser's (2014) qualitative research approach for conducting expert interviews in political science. The latter offers a valuable base for analyzing decision-making processes and mechanisms of power and is therefore helpful for research on public participation. The qualitative interviews were guided along our RQ (How should an XR-based e-participation application be designed to enable public participation in urban planning?). Based on the literature's findings on the distinct challenges and opportunities of AR and VR, we decided to ask about the technologies separately to further explore their differences. Before the interview began, a standardized guideline clarified the research project and made the interview structure transparent to the interviewees. The guideline contained 24 predefined questions, although the interview should be considered semi-structured because the interviewer had the possibility to ask additional questions.

First, we ensured we understood the interviewees' attitudes towards the planned procedures and technologies, considering their backgrounds and prior experience with public participation, citizen participation in construction projects, and e-participation. Second, we introduced the interviewees to the technology and familiarized them with it by showing them the prototype using a smartphone, the postcard with the AR makers, and the HMD (see Figure 3). We gave the participants time to get to know the technologies at their own pace. Then followed questions about the possible degree of participation for an e-participation application in accordance with the SPP. As the application should be modular, with different functionalities addressing different levels of participation, we asked about the different e-participation techniques mentioned (e.g., informing, giving feedback, discussing, voting, etc.) in the context of participating in a construction project. Since participation is voluntary, involvement in public participation projects also depends on incentive concepts. Thereby, we investigated which other elements or design details could make it more likely for them to participate in a construction project via an AR and VR e-participation application. Ultimately, however, the

Figure 3. Illustration of the XR e-participation application: AR version of the construction site (left), visualization of the construction site in VR (right) (Raumtänzer GmbH).

Table 1. Stakeholder groups interviewed and the stakeholders' role within the construction project.

Stakeholder Group	Position/Role
Staff members (10 interviewees)	Directorship, construction management, technical department, finance, public relations, zookeeping
"Friends of" charity organization (3 interviewees)	Fundraisers for the construction project
Visitors (7 interviewees)	Target group for the application, potential donors
City council and representatives (5 interviewees)	City's Spokesperson, Members of the City Council (i.e., responsible for public construction projects)
Technical experts (2 interviewees)	Developers and experts on the usability of the project

aim is to ensure broad participation, which is why a focus on technology acceptance is essential. A final set of questions was hence based on Davis's (1989) and Venkatesh V and Davis's (2000) technology acceptance models (TAM 1 and 2) and the adaptation for digital government research by Pereira et al. (2017). This results in the following research dimensions: "experience and interest", "degree of participation", "incentive concepts", and "technology acceptance".

Based on the above-mentioned study design, in June 2019, we conducted 20 face-to-face interviews, some of which included up to 3 people from the same stakeholder group (see Table A4). To ensure a broad representation of perspectives, we applied a stratified qualitative sampling strategy following Je (1986) using sociodemographic backgrounds and stakeholder roles as important criteria (see Table 1). This approach enabled us to capture diverse experiences and expectations relevant to the participatory setting, while maintaining theoretical consistency across stakeholder groups. The average age of the interviewees was 46 years (min. 18, max. 80, sd. 20.01), 51.85% were female, and 48.15% were male. It is essential to clarify that our interactions with the stakeholders were confined to the scope of this study. Prior to the interviews, we had no previous acquaintance or collaboration with the participants. We recorded the interviews, protocoled the conversations, and then manually transcribed the recordings using MAXQDA. We coded the material and conducted a structured content analysis following the very same method (Kaiser, 2014). This resulted in determining the general attitudes towards the artifact and in exploring the challenges the stakeholders addressed.

4.1.4.1. Experience and interest. Our analysis showed a strong appreciation for digital technologies in public participation: 86% of participants found them valuable and expected them to improve access to information about public construction projects. Additionally, 77% preferred 3D visualizations over traditional plans. When asked whether they were familiar with XR technologies, 60% reported prior knowledge, and only 2 participants reported personal experience with XR technologies. The design of future applications should leverage VR and AR visualizations to include non-experts in construction planning.

4.1.4.2. Degree of participation. We observed that the interviewees were willing to participate only through an e-participation application up to a certain point. While most participants embraced the idea of informing themselves through the application, the readiness to get involved with the project sank in accordance with the increase in the level of participation, according to the SPP. Most participants were willing to learn about the project through the application, but many were less willing to engage in more interactive forms of participation, such as commenting or discussions. The latter, in many cases, was caused not only by the citizens' doubt in their own competence: project initiators, too, raised concerns about the former's ability to participate due to their lack of expertise. Besides, the question arose of how to achieve representativeness, ensure a minimum level of submission quality, and prevent polarization of opinions, which can occur on loosely moderated platforms. While showing interest in aspects of crowdfunding (donating to projects they affirm), many participants' willingness to participate in a participatory budgeting process for a construction project was weaker, again due to their perceived lack of competence.

4.1.4.3. Incentive concepts. Initiators emphasized the need for transparent communication of participation scope. Users valued recognition of their contributions and wanted assurance that their input would impact decision-making, despite the challenge of reaching consensus.

4.1.4.4. Technology acceptance. Perceptions of VR and AR differed. AR was seen as informative, often related to construction, while VR was more associated with gaming and visualizing new spaces. The likelihood of participating in a new construction project increased by 74% among interviewees who used these technologies. Although most had no reservations about using AR and VR for e-participation, some expressed concerns about data protection. Participants highlighted the need for the application to be low-barrier, easy to use, and intuitive, to counteract digital divide exclusiveness and enhance representativity. Some called for open-source applications for better transferability and accessibility.

4.2. Second cycle

4.2.1. Problem awareness: reflection of the first cycle

Design knowledge development: Conducting stakeholder mapping and a qualitative study in the first cycle clarified the concept of using XR for e-participation. The qualitative study confirmed some persona-based assumptions but also revealed the need to revise others. The interviews highlighted the need for transparent communication, as we underestimated how strongly both citizens and initiators may question citizens' competence to contribute. Basic design recommendations, such as social media connectivity and format transferability, were also explored.

The identified strengths and weaknesses of AR and VR in the first cycle support the idea that combining both technologies for an e-participation application is a promising research field. Reflecting on the first cycle, we aimed to derive meta-requirements and design principles.

4.2.2. Suggestion: meta-requirements and design principles

The structured content analysis allowed us to map the potential and challenges of an AR- and VR-based e-participation application from the perspectives of various stakeholders. The level-specific challenges identified in the qualitative material translate into five meta-requirements.

At the inform level, the central challenge concerns entry barriers, cognitive overload, and low confidence in navigating immersive environments, making orientation and gradual competence-building critical. At consult, participation needs shift toward avoiding ungrounded or abstract feedback, requiring mechanisms that anchor contributions in spatial context and enhance actionability. Moving to involve, the key challenge becomes drop-off and fragmented participation, as sustained engagement depends on visible responsiveness and reciprocal interaction; in the qualitative interviews, participants emphasized the importance of visible responsiveness and progress to remain engaged. At the collaborative level, collective deliberation introduces requirements for facilitation and transparent process structures to maintain procedural legitimacy, especially under heightened social presence. Finally, empowerment entails higher-stakes influence and perceived impact, where trust, privacy, and perceived exposure risk make data governance and safeguards enabling conditions for participation.

Through this analysis, it became clear that the different SPP levels cannot be mapped one-to-one to five distinct requirements because of overlapping needs across levels. For example, interviewees made it clear that they only wanted to participate to a certain extent. Therefore, easy access and low entry barriers would not only be required for SPP level 1 (inform), but also for progressing to higher SPP levels. Trust and privacy are particularly important for level 5 (empower), but they are also related to the participant's impact on decision-making at lower levels (involve). We left it to our subsequent design cycles to further understand these relationships between design principles and SPP levels, in the hope of arriving at a potential mapping between these two.

Based on our analyses and empirical findings, we derived five meta-requirements for an XR-based e-participation application: addressing users' access to the application (MR-1), their need for specific information (MR-2), and their motivation to use the application (MR-3). Additionally, the analysis showed the necessity of transparent communication of the project's intentions (MR-4) as well as data security (MR-5). The meta-requirements shall further determine five general design principles (Chandra et al., 2022; Gregor & Jones, 2007) for the development of an XR e-participation application (Table 2).

4.2.3. Development: revised artifact design

In a collaborative workshop with the system development team, we presented our qualitative study findings and discussed the meta-requirements and initial design principles. We engaged in detailed discussions to integrate these findings into the application's further development, and the system development team developed technical solutions.

Feature evolution: The technical realizations show how features evolved in response to the MR and DP, based on the evaluations (see the last column in Table 2). For example, the development team exploited the visual and informative potentials of both AR and VR by allowing a transition from 2D to 3D. The AR application in the prototype allowed users to visualize the construction project through markers on a poster and switch to a panoramic tour (see Figure 4). During the tour, users could move around the virtual island and observe ring-tailed lemurs. The VR component included an HMD (Oculus Quest) with a 3D model of the island, also featuring moving lemurs. Users could navigate and view the island from different perspectives using two controllers. In sum, the 2D-3D transition feature arose from the interviewees' feedback in study one of seeing both merit in AR and VR (technology acceptance), while the possibility to navigate on the island and experience the landscape and objects in 3D resulted from the feedback from the first part of the interview (experience and interest).

As another example of feature evolution, the system development team, together with the researchers, introduced a new dashboard feature with various participation modules, increasing transparency in the participation process. Based on the interviewees' feedback that they doubted their own competence and

Table 2. Meta-requirements and initial design principles for XR-Based e-participation.

Meta-Requirement	Description	Design Principles	Exemplary instantiations (feature-level)
Access (MR-1)	MR-1.1 Intuitive and efficient navigation throughout the application MR-1.2 Application portability through access via various mobile devices that fulfill the respective AR and VR hardware requirements MR-1.3 Connect to social media to address new users MR-1.4 Offer crowdfunding through a donation process that offers online and offline payment methods MR-1.5 Allow transferability between projects (through open-source access, modular design, and interoperability)	DP1 Reduce participation barriers through ensuring broad access and targeting groups with low participation or technical expertise	– Native Xamarin framework for seamless user experience – Unity content integration as a plugin within the Xamarin-based app – Format-independence to increase device-compatibility – Availability of modules and plugins for every project, including simultaneous updates for improvement – Simplified user interface with clear labels and icons that require minimal technical knowledge to navigate
Information (MR-2)	MR-2.1 Use the strength of the visualization to inform: (1) in an interactive manner through AR and (2) in an entertaining manner through VR MR-2.2 Offer information that addresses different stakeholders (e.g., citizens, experts), ranging from a general overview to technical details MR-2.3 Convey the urgency of the project's impact and the need to participate MR-2.4 Empower the users to participate by increasing their competence	DP2 Highlight the project's relevance and exploit the visual and informative potentials of AR and VR to address the needs of different stakeholders	– Implement the possibility to transition from 2D to 3D visions – Animated 3D objects and panoramic tours – Users can switch between the display of alternative building elements in real time – Situational anchors to link information and feedback to specific spatial contexts – Users can be informed about selected project progress via push notifications
Motivation (MR-3)	MR-3.1 Provide updates on the project's progress to keep the users informed and involved in the project after the initial participation process MR-3.2 Empower users to feel able to participate, especially when it comes to voting, participatory budgeting, and submitting design suggestions MR-3.3 Encourage participation through the consideration and recognition of citizen feedback MR-3.4 Incentivize donations by using the expected effect of visualization on the interest in a project MR-3.5 Moderate discussions to ensure a respectful environment	DP3 Motivate proactive participation and interest through up-to-date information, and by recognizing the participation	– Interactive chat window with the project, similar to well-known instant messengers – Allow different kinds of participation, such as comments, upvoting, attaching suggestions – Interaction cues and recognition elements to make responsiveness visible (e.g., contribution status indicators)
Transparency (MR-4)	MR-4.1 Outline the initial motivation of the participation process MR-4.2 Make the scope of influence transparent to the users MR-4.3 Ensure communication of the results to the decision-making bodies MR-4.4 Ensure a fully transparent donation process	DP4 Make the aim and scope of the participation process transparent	– Using a combination of text, visuals, and short video explanations for a simple description of the purpose and scope of the project – Feedback options can be activated individually by the project supervisor – An interactive timeline can be used to show participants where their input fits in the overall process
Data Security (MR-5)	MR-5.1 Possibility to learn about and gain trust in the use of personal data MR-5.2 Ensure secure payment	DP5 Ensure and communicate data security measures	– Privacy-preserving sensor data processing (data minimization and purpose limitation) – Adjustable transparency controls (user-facing settings for data sharing, visibility, and consent)

needed more empowerment, voting mechanisms were introduced that visualized the alternatives (see Figure 5). Such features were hoped to motivate proactive participation and increase transparency (DP3 and DP4).

4.2.4. Evaluation: quantitative study and its results

The quantitative study evaluating the second cycle prototype focused on answering the RQ (How should an XR-based e-participation application be designed to enable public participation in urban planning?). Conducted over five days at a significant consumer fair in Karlsruhe, visitors could participate in the demonstration using the AR and VR e-participation artifacts. The setup included two tablets with AR applications and an HMD (Oculus Quest) for VR. Participants (339 total, 57% AR, 43% VR) completed a 17-question questionnaire: 12 testing meta-requirements on 7-point Likert scales and 5 on demographics and feedback. The average participant age was 40 years, with 63.8% female and 36.2% male, showing no gender ratio difference between groups

Figure 4. The new construction project on a tablet including a survey module (Raumtänzer GmbH).

Figure 5. Voting Mechanism in the application; decision on different versions of the visualization (Raumtänzer GmbH).

($p = .648$). All items from the study questions are shown in Table A1 in the Appendix, and the results are in Table 3. The highest values were for MR-2.2 and 2.4 on informativeness of the visualization (IV). Participants rated the application's help in imagining the new enclosure (IV1 – see Table A1 in the Appendix) at a very high level of 6.23. They agreed that the demonstrator clarified the construction project's dimensions (IV3) with a mean of 5.61. VR was rated significantly higher than AR for these questions ($p < .001$). Participants guessed the new enclosure size compared to the old one (IV2), with 30.28% correctly answering "twenty times bigger". Although over half preferred the XR technologies (IV4), one-fifth were neutral, indicating some hesitation about using them for new projects.

The qualitative study highlighted different perceptions of AR and VR, and therefore, we used perceived telepresence (Ff-H et al., 2011; T. Kim & Biocca, 1997; Lr, 2003) to test MR-2.1. VR scored higher in perceived telepresence (mean 5.37) than AR (mean 4.23) ($p < .001$). VR's high telepresence creates an entertaining experience, distracting users more from their immediate surroundings than AR does. MR-3.2 was tested by asking participants how the application motivated them to engage with the construction

Table 3. The results of our questionnaires of the Second and third cycle study.

Item/MR			Aggregated (mean(SD))	AR (mean(SD))	VR (mean(SD))	p (AR vs. VR)
Intuitive navigation (IN)	IN1, MR-1.1		5.88 (1.29)			
	IN2, MR-1.1		5.51 (1.43)			
	IN3, MR-1.1		5.96 (1.23)			
	IN3, MR-1.1		5.29 (1.42)			
	IN, (Mean of IN 1–4), MR-1.1		5.54 (1.36)			
Social media connection (SM)	SM, MR-1.2		5.47 (1.54)			
Information detail (ID)	ID, MR-2.2		5.42 (1.29)			
Information urgency (IU)	IU, MR-2.3		5.99 (1.16)			
Informativeness of the visualizations (IV)	IV1, MR-2.2; 2.4		6.23 (1.08)	6.08 (1.08)	6.46 (0.96)	<.001[a]
	IV2, MR-2.2; 2.4	Correct	99 (30.28%)	56 (29.63%)	43 (30.94%)	1[b]
		False	228 (69.72%)	133 (70.37%)	95 (69.06%)	
	IV3, MR-2.2; 2.4		5.61 (1.25)	5.38 (1.24)	5.94 (1.14)	<.001[a]
	IV4, MR-2.2; 2.4		3.29 (1.83)	3.32 (1.77)	3.26 (1.92)	.622[a]
Perceived telepresence (PT)	PT, (Mean of PT1-3), MR-2.1		4.71 (1.49)	4.23 (1.48)	5.37 (1.2)	<.001[a]
Motivation to participate in the project (MP)	MP, MR-3.2		4.75 (1.43)	4.55 (1.41)	5.05 (1.39)	.001[a]
Willingness to donate (WD)	WD, MR-3.4		4.32 (1.73)	4.22 (1.67)	4.48 (1.78)	.157[a]
Moderation of discussions (MD)	MD1, MR-3.5		5.34 (1.52)			
	MD2, MR-3.5		5.41 (1.54)			
	MD3, MR-3.5		2.93 (1.54)			
	MD (Mean of MD1-3), MR-3.5		4.56 (1.53)			
Personal data and trust (DT)	DT, MR-5.1		5.60 (1.15)			
Artifact's usefulness for further cases (AU)	AU1, MR-1.5	Yes	227 (69.63%)	126 (68.48%)	101 (71.13%)	.395[b]
		No	12 (3.98%)	5 (2.72%)	7 (4.93%)	
		Poss	87 (26,69%)	53 (28.80%)	34 (23.94%)	

Note: p-values based on: a = Mann-Whitney U test, b = chi-squared test; if the AR, VR and p column remain empty, it is because the low and high immersion group were merged in the second quantitative study.

project (MP), following Naranjo-Zolotov et al. (2019). The mean motivation score was 4.75 and higher in VR than AR ($p = .001$).

To test if visualization incentivizes donations (MR-3.4), we asked if the demonstration increased donation willingness (WD). With a moderate willingness score of 4.32, almost half reported feeling more willing to donate after using the demonstrators, suggesting potential for combining e-participation with crowd-funding. No significant difference was found between AR and VR ($p = .157$).

We tested artifact usefulness (MR-1.5) by asking if participants could imagine using a similar application for other projects. 69.63% responded positively, while only 3.98% said "no", demonstrating resonance of an AR and VR e-participation artifact for construction projects. No significant difference was found between AR and VR ($p = .395$).

Furthermore, we tested whether prior technology experience and age affected attitudes (MP and AU1). A significant negative effect of age ($p < 0.05$) on motivation to participate (MP) was observed in a linear regression with AR/VR as the independent variable and MP as the dependent variable.

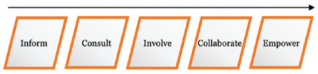
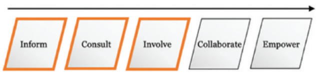
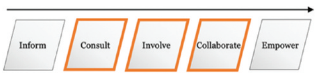
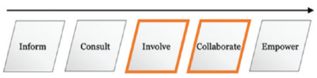
Summarizing the results of the second cycle, we observed strong interest in using AR and VR for e-participation to better visualize construction planning. The prototype significantly aided project imagination, especially with VR. However, preference for AR and VR visualizations over non-digital miniature models was not very strong. Miniature models are popular but limited by their fixed location, while XR can be accessed anywhere. Participants valued the informativeness of the visualizations, which often made users feel virtually transported to the project site—an effect described as telepresence. VR's higher rating than AR might result from its greater telepresence. Nevertheless, comparisons between AR and VR are limited since the AR prototype wasn't shown in situ. Usually, AR allows users to see construction planning at the real construction site with added digital content, improving the attractiveness. Modest scores for motivation, willingness to engage, and willingness to donate, along with doubts about competence, suggest potential to enhance motivation through design improvements. Given that willingness to participate varied based on participation levels, the upcoming third cycle should investigate motivating factors of immersive e-participation tailored to specific levels of participation.

4.3. Third cycle

4.3.1. Problem awareness: reflection of the previous cycles

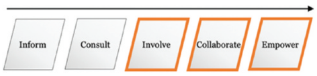
Design knowledge development: We aligned the design principles with the practical experience gained during the development process and the findings from the quantitative study of the second cycle (see Table 4), thereby helping to create "cumulative bodies of design knowledge" (Gregor et al., 2020). To strengthen their conceptual clarity and prescriptive utility, we systematically reformulated the principles following the design-principle schema proposed by Gregor et al. (2020), which emphasizes the explicit articulation of aim, implementers, users, context, underlying mechanisms, and theoretical rationale. This structured approach resulted in revised design principles that are

Table 4. Refined design principles for XR-Based E-Participation.

Design Principle 1	**Enable SPP-Aligned Access and Progression through Configurable XR Navigation**
Aim, Implementer, and Users	For XR designers and participation providers to make participation stages transparent and accessible to heterogeneous publics.
Context	In XR-based e-participation settings, where citizens differ in digital skills, prior knowledge, and expectations regarding participation.
Mechanism	Embed the SPP as an explicit, configurable navigation structure within the XR interface. Provide stage-specific entry points, explanations of participation scope, and consistent transitions across participation levels. Develop intuitive, low-barrier and interoperable XR interfaces using frameworks that enable seamless user experience and high-quality 3D content integration. Allow for voice commands, and gesture-based controls optimized for use in public spaces.
Rationale	By applying the SPP as an explicit process model rather than an implicit backdrop, DP1 enables users to orient themselves within the participation process and supports deliberate configuration by participation providers across all SPP levels (inform–empower). Kernel-Theory-Based SPP-Mapping:  DP1 ensures that all citizens can access and use XR tools, regardless of background or ability. This inclusivity is foundational to every level of the SPP – from informing to empowering – as meaningful participation cannot occur without accessible entry points.
Design Principle 2	**Support Situated Understanding and Actionable Feedback through Anchoring and 2D–3D Transitions**
Aim, Implementer, and Users	For XR designers and participation providers to enable meaningful understanding and feedback in spatially complex participation contexts.
Context	In XR-based planning scenarios where abstract proposals must be understood, assessed, and commented on by non-expert publics.
Mechanism	Implement the possibility to transition from 2D to 3D visions, interactive 3D models and simulations. Allow for spatial annotations by situational anchors that allow users to explore and engage with planning content in real time and with clear reference to the exact location in the real environment. Integrate push notifications to convey the need to participate.
Rationale	Anchoring information and feedback and allow for 2D to 3D transitions within an immersive spatial context transforms participation from abstract interpretation into situated interaction that cannot be achieved through non-immersive representations alone. Kernel-Theory-Based SPP-Mapping:  DP2 enhances citizens' spatial comprehension and contextual awareness. These affordances support the inform, consult, involve, stages of the SPP, where informed dialogue,
Design Principle 3	**Sustain Participation through Moderated and Acknowledged Social Interaction**
Aim, Implementer, and Users	For participation facilitators to support continued engagement beyond one-off contributions.
Context	In XR-based e-participation environments, where social presence is high and sustained engagement is required across longer planning processes.
Mechanism	Provide mechanisms for moderated interaction, visible acknowledgment of contributions, and responsive feedback loops (e.g., curated discussions, response indicators, contribution status). Simulate social co-presence by gamification elements such as voting and leaderboards.
Rationale	Sustained participation is supported when interactive and motivational elements are embedded in socially mediated and institutionally acknowledged processes, reinforcing participants' perceived impact at higher SPP levels. Kernel-Theory-Based SPP-Mapping:  DP3 can enhance users' motivation and sense of belonging because they encourage sustained interaction and community dialogue, aligning with the consult, involve, and collaborate levels of the SPP, which support increasingly active and shared forms of participation.
Design Principle 4	**Strengthening Perceived Legitimacy through Traceable and Explainable Participation Processes**
Aim, Implementer, and Users	For participation providers and facilitators to communicate how citizen input is processed and acted upon.
Context	In participatory processes where legitimacy, accountability, and transparency are prerequisites for collective decision-making.
Mechanism	Implement traceability features such as dashboards, walkthroughs, and audit trails that explain how contributions are collected, aggregated, and integrated into decisions.
Rationale	Process transparency enables participants to understand the consequences of their input, strengthening legitimacy and confidence, particularly where deliberation and coordination are required. Kernel-Theory-Based SPP-Mapping:  DP4 demonstrates to users how input is collected, processed, and acted upon. This visibility fosters trust and encourages continued engagement – especially vital at the involve and collaborate levels of the SPP, where reciprocal communication and shared understanding underpin effective joint decision-making.
Design Principle 5	**Enable Trust through Privacy-Preserving Data Practices and Adjustable Transparency Controls**
Aim, Implementer, and Users	For XR designers and participation providers to support high-stakes e-participation under conditions of perceived exposure and accountability.

(*Continued*)

Table 4. (Continued).

Context	In XR-based e-participation scenarios involving sensor data, personal text inputs, and public visibility within publicly governed and legally regulated participation processes.
Mechanism	Ensure GDPR-compliant hardware and software, including data minimization, adjustable privacy settings, and opt-in anonymization. Implement GDPR-compliant, privacy-preserving data practices (e.g., data minimization, purpose limitation, encryption, consent-based processing) combined with adjustable transparency controls that allow participants to manage data visibility, anonymity, and purpose-specific use while ensuring institutional accountability
Rationale	At higher SPP levels, participation entails increased perceived risk and exposure. Trust therefore becomes an enabling condition rather than a byproduct of participation. By combining legally grounded data protection (GDPR-compliant) with user-controllable transparency mechanisms, the system reduces perceived risk, reinforces institutional legitimacy, and supports sustained participation at empower-level engagement. Kernel-Theory-Based SPP-Mapping:  DP5 builds the foundational trust needed for deeper, long-term engagement. By addressing privacy concerns and ensuring responsible data use, XR systems create the legitimacy necessary for participation at the involve, collaborate and empower levels of the SPP – where citizens must feel confident that their input is respected, protected, and impactful.

more theory-informed, operationalized, and conducive to implementation and evaluation in both research and practice. Due to the refined design principles and our increased understanding of the problem, we were able to use the SPP to align each design principle with varying depths of participation, ranging from informing and consulting to involving, collaborating, and empowering citizens (see “SPP Mapping” in Table 4).

4.3.2. Suggestion: applying the experiential implications of the design principles

The design principles summarized in Table 4 specify how XR-based e-participation systems can be designed to support participation across different SPP levels by applying access, understanding, engagement, legitimacy, and trust through concrete design mechanisms. Beyond prescribing design actions, these principles also imply how participants are expected to experience these systems as they move through the participation process.

In particular, DP1 and DP4 target users’ ability to orient themselves within the participation process and to understand how their input is handled, thereby shaping familiarity with the decision context and confidence in the legitimacy of the process. DP2 translates abstract planning information into situated, actionable representations that are expected to foster familiarity and confidence in decision-making. DP3 addresses sustained participation by embedding social interaction and institutional acknowledgment, thereby shaping enjoyment and perceived impact. Finally, DP5 establishes conditions under which trust and confidence can emerge at higher SPP levels by combining privacy-preserving data practices with transparent governance mechanisms.

To inform the further development and summative evaluation of the artifact, these implied experiential effects need to be examined. Drawing on prior information systems and e-participation research, we therefore use enjoyment, familiarity, and confidence and their variations across SPP levels as evaluative lenses through which the effects of the proposed design principles can be assessed (Gefen et al., 2003; Hassan & Hamari, 2020; X. J. Li et al., 2008; Rigby, 2015; Scherer & Wimmer, 2014). These constructs are not introduced as additional design goals, but as established cognitive and motivational dimensions that allow us to examine whether the design mechanisms specified in Table 4 translate into conditions known to support sustained and meaningful e-participation.

4.3.3. Development: final implementation into the artifact

Feature evolution: The subsequent section provides an overview of technological advancements and their alignment with revised design principles from the previous DSRIS cycle. The development team refined the app menu and structure to reflect the current participation focus (see situational anchor in Figure 6 left). These anchors include image uploads, panoramic tours, and AR or VR models created by the project initiator.

The app’s bottom navigation bar simplifies navigation in the complex immersive environment and reflects the SPP for implementing DP1. The development team introduced situational anchors (DP2) that integrate participation modules such as information, discussions, annotations, and surveys, overlaying the background as a transparent window for interaction.

The third development stage improved the immersive experience, enhancing realism and engagement. To transition from 2D plans to a 3D vision (DP2), the app offers AR and VR visualizations (see Figure 6 right). AR allows citizens to scan a marker to display the planned object in the real world, while VR lets users explore the site virtually.

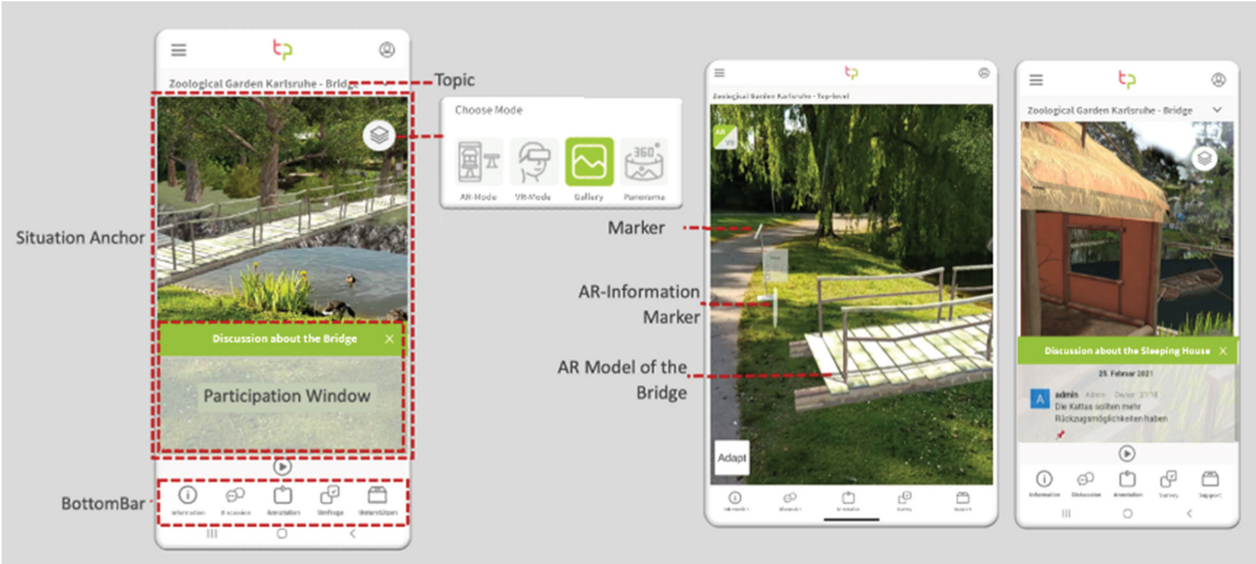


Figure 6. The menu and structure of the app (left), the AR view (middle), and the VR view (right).

The development team addressed discussion challenges (DP3) by introducing situational anchors linking contributions to specific contexts. This incorporates a chat feature for discussions and supports annotations, allowing comments, audio recordings, images, or additional comments in the immersive environment. Initiators can set up configurator signs for visual experiences without technical drawings, and users can participate in surveys or share opinions through comments, upvotes, or suggestions (see Figure 6). To support DP4, the artifact includes transparency elements (e.g., onboarding walkthroughs and contribution-status indicators) that clarify how inputs are collected and taken up over the participation levels. To support DP5, the app implements GDPR-aligned safeguards (e.g., consent-based processing, data minimization, and privacy-preserving defaults), complemented by adjustable settings for visibility and anonymization.

Implementing AR and VR content in mobile apps requires an optimal user experience and performance. The app combines two technological approaches: a native Xamarin framework for seamless user experience and Unity for high-performance AR and VR 3D applications. AR libraries (ARCore for Android and ARKit for iOS) ensure stable tracking. Unity content is integrated as a plugin within the Xamarin-based app, providing a cohesive and immersive experience that facilitates accessibility. Following the DSRIS approach, developers incorporated the researchers' results and suggestions.

4.3.4. Evaluation: final quantitative study

One significant challenge encountered in our study was the difficulty of achieving an adequate sample size during in-person data collection. A notable factor contributing to this issue was the presence of visitors accompanied by children. Many parents and caregivers attending the event with their children demonstrated limited capacity to participate in research activities. As a result, the anticipated sample size could not be realized, necessitating the consideration of alternative data collection methods. Therefore, together with the development team, we pivoted to an online study to demonstrate and assess XR-based e-participation compared to traditional e-participation. This approach presented challenges, such as simulating realistic participation without direct AR and VR interaction and adapting the platform for non-immersive devices. The development team developed an alternative to allow participants to perceive differences between two treatment groups: one simulating e-participation with high-immersive systems and the other with non-immersive systems. This remained challenging as the application was primarily designed for mobile devices and HMD. Although there are examples of studying immersive systems using browser-based simulations (Jiang et al., 2018; MacIntyre & Smith, 2018), this effort was a fallback solution in response to the unexpected circumstances of the pandemic.

The study was conducted from September 20 to 24, 2021, with 382 participants recruited by a research lab. Participants were randomly divided into two groups: "high immersion", with a clickable, interactive 2D app version, and "low immersion", with static images and text. Both groups received instructions via email to conduct the study on their own devices.

The experiment began with a textual explanation of the zoo's construction project, followed by a 4-minute video about the use case, shown only to the high-immersion group. The study reflected the five SPP levels, starting with "inform", where the low-immersion group saw static images, and the high-

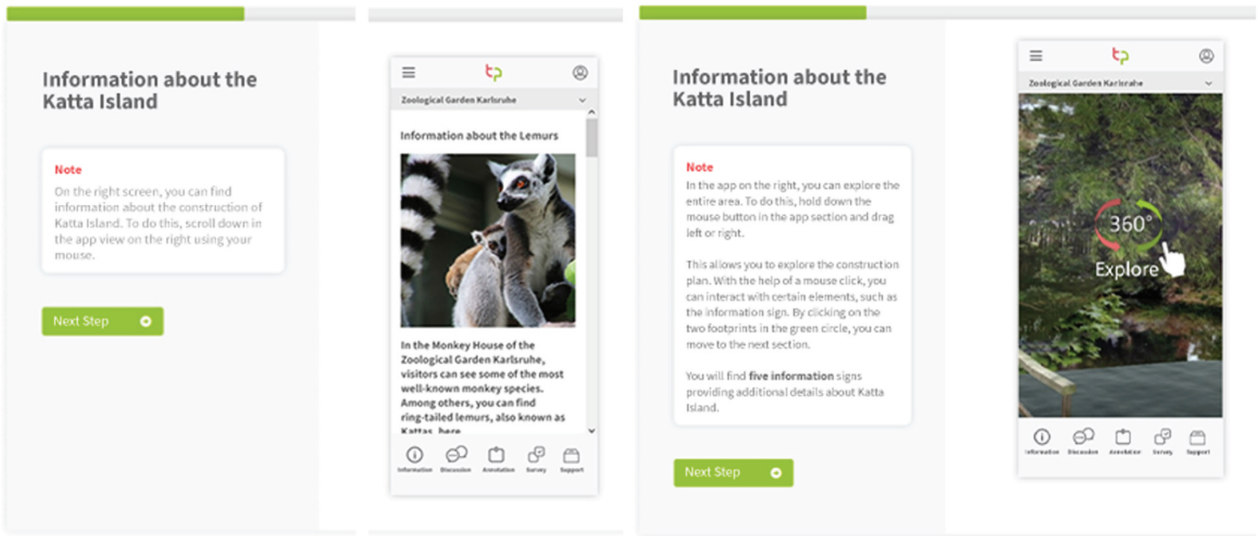


Figure 7. Simulation for the information Level of participation. While the low immersion group (left) saw static images and text of the environment, the high immersion treatment group (right) was shown a dynamic and interactive 360 degree environment, where information appeared inside the environment (Raumtänzer GmbH).

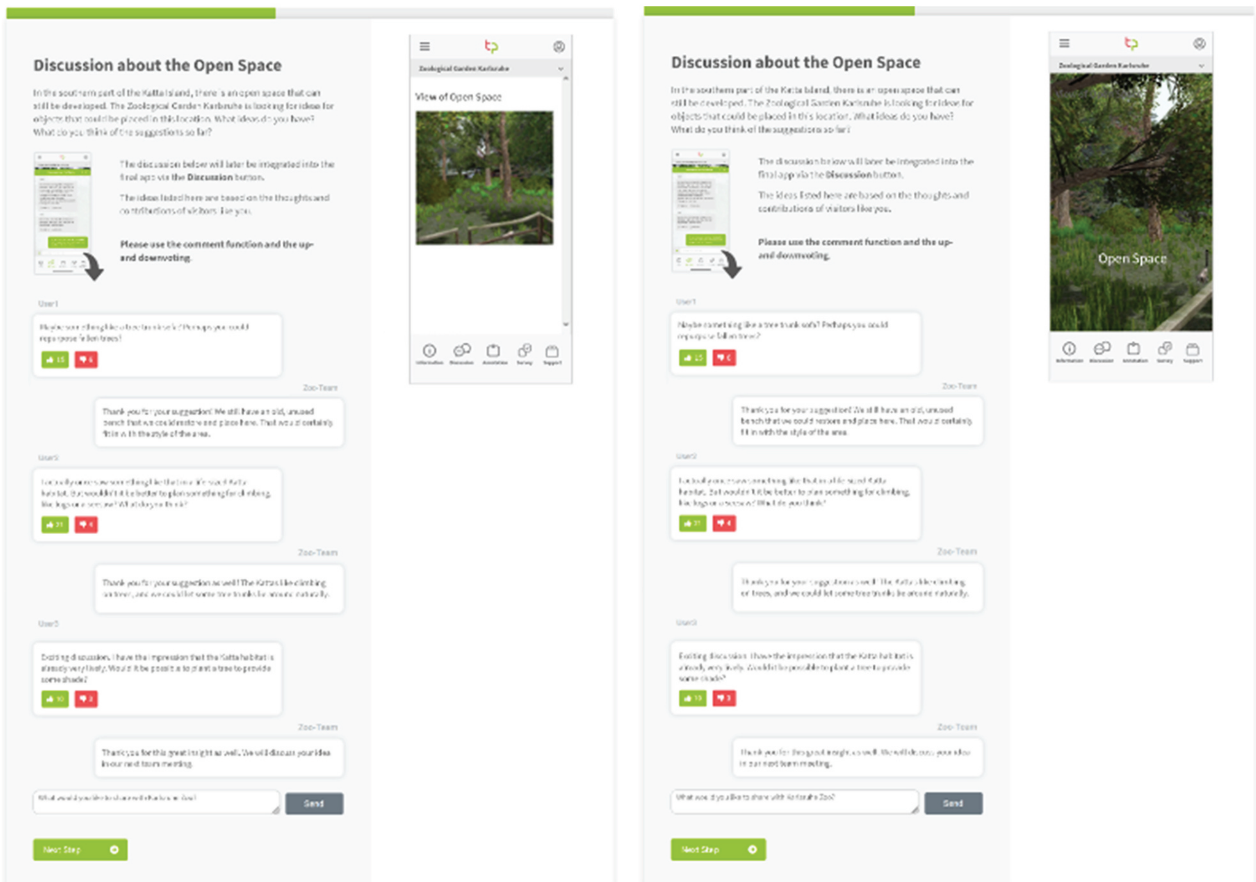


Figure 8. Simulation for the involvement Level of participation. While the low immersion group (left) saw static images of the environment, the high immersion treatment group (right) saw an interactive environment (Raumtänzer GmbH).

immersion group explored interactively (see Figures 7 and 8). In "consult", participants used feedback mechanisms. In "involve", they influenced discussions through voting and comments. "Collaborate" allowed direct interaction with design choices, and "empower" involved making binding design decisions.

After the experiment, we compared participants' perceived telepresence between the two treatments. A t-test on the mean scores for all three telepresence items (Cronbach's alpha = 0.86) showed no significant difference between the test and control groups (3.76 vs 3.67, $t(379.12) = -0.66$, $p = 0.507$)). Therefore, the results of both groups were reported together to show overall user feedback on the artifact, pending MR, and continuous participation motivation.

4.4. Usefulness of the artifact

4.4.1. Pending meta-requirements

The study evaluated various meta-requirements using a 7-point Likert scale, focusing on intuitive navigation, detailed information distribution, social media integrations, moderated discussions, motivational factors, and privacy measures. Participants valued the app's intuitive navigation and preferred detailed information distribution. They showed interest in using social media connections for e-participation and preferred moderated discussions over anonymous participation. The findings emphasized the importance of personal interest, consideration of feedback, and notifications as motivational factors, as well as the need for privacy measures to build trust among users (see Table A1 in the Appendix and Table 3).

4.4.2. Continuous participation motivation

After the interaction with each of the five app features that supported the five different participation levels, we asked participants for their enjoyment ("I enjoyed reviewing the information"), familiarity ("The presentation of information helped me become familiar with the decision context".) and confidence ("The provided information and its presentation enhanced my decision-making confidence".). Table 5 summarizes the descriptive statistics for the three measures.

A multilevel model with participants as random effect shows a significant effect of the SPP participation levels 1 to 5 on enjoyment ($\chi(10)=122.07$, $p < 0.001$)), familiarity ($\chi^2(10)=91.28$, $p < 0.001$), and confidence ($\chi^2(10)=164.80$, $p < 0.001$). Post-hoc tests with Tukey's procedure revealed a significant increase of enjoyment for increased levels of participation except for the difference between level 1 and level 2 ($p = .1$) as well as level 4 and level 5 ($p = .80$). For familiarity, again most of the times an increase in the participation level leads to increased familiarity except for the difference between level 1 to level 2 ($p = .97$) and level 3 (.97) and level 2 to level 3 ($p = 1$) and level 4 to level 5 ($p = .74$). The results for confidence are similar to familiarity with no difference between levels 1 and 2 ($p = .61$), levels 2 and 3 ($p = .1$), and levels 4 and 5 ($p = .89$). The results of the post-hoc tests can be found in Tables A2 and A3 in the Appendix. As a robustness check, we also computed the analysis with repeated-measure ANOVAs using Greenhouse-Geisser corrections because of violated sphericity and Bonferroni corrections for the post-hoc tests. The results are comparable.

The study's findings strongly support the argument that increased participation leads to better outcomes (see Tables A2 and A3 in the Appendix). Among all three variables standing for the motivational aspects (enjoyment, familiarity, and confidence), there were no significant differences between SPP levels 1–2 and 4–5. In addition, there was no increase between 2–3 for familiarity and confidence. This indicates that the strongest increase occurs between levels 2–4, and that increasing participation by just one level might not yet lead to the intended effects on motivation. Very promising are changes across at least two participation levels, as all of them showed good effects. For an increase from 2–4, for example, all three measures increased by an estimate of 0.437 to 0.670 on the 7-point Likert scales. In sum, while acceptable levels of around 5.14 to 5.5 can be achieved with level 1 (inform), it seems worthwhile to increase to the higher levels 3–5, with values up to 6.09. Drawing a parallel to Arnstein's classification of "degrees of tokenism" and "degrees of citizen power" (Arnstein, 1969), our proposed form of participation demonstrates a particularly motivating effect at higher levels of the SPP, making it preferable for those levels. This finding is especially interesting, as the first qualitative study showed the doubts both citizens and initiators had about higher forms of participation. If our artifacts are successful in improving enjoyment, familiarity, and confidence at higher SPP participation levels, our XR artifact certainly adds value to classical forms of e-participation.

Summarizing the third DSRIS cycle, we evaluated the final artifact and gained insights into how different levels of participation shape users' perceptions and experiences when interacting with the XR-based e-participation application. The study examined whether users' responses varied systematically across SPP levels. One central finding is that higher levels of participation are associated with increased motivation, reflected in rising levels of enjoyment, familiarity, and confidence.

Table 5. Descriptive statistics for enjoyment, familiarity, and confidence across SPP levels.

Item / Level of Participation (SPP)		Level 1 Inform	Level 2 Consult	Level 3 Involve	Level 4 Collaborate	Level 5 Empower
Enjoyment	Mean (SD)	5.14 (1.35)	5.13 (1.38)	5.46 (1.27)	5.74 (1.21)	5.83 (1.22)
Familiarity	Mean (SD)	5.50 (1.23)	5.55 (1.32)	5.55 (1.19)	5.99 (1.19)	6.09 (1.12)
Confidence	Mean (SD)	5.17 (1.27)	5.29 (1.44)	5.50 (1.24)	5.96 (1.25)	6.04 (1.15)

Participants' high ratings of familiarity and confidence are consistent with design principles targeting orientation and transparency (DP1, DP4). In particular, intuitive navigation structures and traceable participation processes appear to have reduced perceived barriers for non-expert users, supporting users' ability to orient themselves within the process and to understand how their input was handled. Rather than confirming initial concerns about a lack of competence at higher participation levels, the results indicate that deeper involvement can strengthen participants' sense of agency and empowerment.

5. Discussion

5.1. Design knowledge and implications

Building on the artifact development and evaluation, we summarize the study's implications and contributions in terms of design knowledge and theory-informed guidance. The central contribution of this study lies in a set of meta-requirements and design principles that translate abstract participatory goals into actionable design knowledge for XR-based e-participation. In doing so, the study addresses calls for more prescriptive, theory-informed design knowledge in XR-based e-participation research (Simonofski et al., 2024), particularly the need to connect participatory depth with concrete system functionalities. The design principles derived from the three DSRIS cycles specify how immersive technologies must be configured differently depending on whether participation aims to inform, consult, involve, collaborate, or empower citizens. Thereby, they move beyond generic XR affordances and articulate prescriptive guidance for aligning interaction design, social mediation, and institutional accountability with participation depth.

Concretely, the design principles link participatory goals to technical and interactional mechanisms such as SPP-aligned navigation structures, 2D to 3D transitions, situational anchors that connect contributions to spatial context, moderated and acknowledged social interaction, traceable participation processes, and privacy-preserving data practices. For example, the use of a navigation bar reflecting all stages of the SPP operationalizes participation transparency and orientation, while situational anchors enable context-specific contributions grounded in lived spatial experience. These mechanisms demonstrate how XR features can be purposefully deployed to reduce cognitive effort, support informed deliberation, and sustain engagement across participation levels.

From a design knowledge perspective, the novelty of this study does not lie in the use of XR technologies per se, but in the systematic coupling of immersive system features with participation depth and institutional responsibilities. Prior XR-based participation approaches primarily emphasize visualization fidelity, presence, or user experience in isolation (Porwol & Ojo, 2019; Simonofski et al., 2024; Stein & Fegert, 2024; Stein et al., 2025, Fegert et al., 2019, 2020). In contrast, our design principles embed participation depth as a configurable design dimension, showing how immersive affordances, social interaction mechanisms, and governance requirements must co-evolve to support meaningful e-participation. In this sense, the study extends existing XR and e-participation frameworks by providing prescriptive and transferable design knowledge grounded in a well-established participation theory.

With respect to kernel theory contribution, this study demonstrates how the SPP can be applied as a design theory rather than a descriptive participation framework. By explicitly mapping design principles and system mechanisms to participation levels, we show how democratic ideals such as meaningful involvement (Pateman, 2012) and participatory parity (Fraser, 2014) can be translated into concrete design decisions concerning navigation, interaction modalities, transparency, and data governance. Our empirical findings further indicate that higher levels of participation are associated with increased enjoyment, familiarity, and confidence, suggesting that carefully designed XR-based e-participation can lower perceived participation barriers and foster empowerment among non-expert citizens.

Taken together, the presented design principles contribute to a socio-technical understanding of e-participation that aligns structural participation levels with normative commitments to inclusivity, transparency, and democratic legitimacy. By grounding immersive system design in participation theory and empirically evaluating its effects across participation stages, this study advances design-oriented research on XR-based e-participation and directly addresses the question of how such systems must be designed to enable meaningful e-participation in urban planning.

5.2. Limitations and future research

This research has several limitations that need to be acknowledged, which also point towards important directions for future research. First, the generalizability of the findings is constrained by geographical and contextual focus. E-participation, as well as traditional public participation, is often shaped by local socio-political dynamics, and our study focuses on a single use case in a strong economic region in southern Germany. While there may be comparable settings in Europe and the Americas, variations in trust in government and in the willingness to participate through e-participation platforms could influence results and require adaptations to the design. For example, the well-functioning public administration of our case city may have contributed to higher engagement. In regions with less trust in government and organizations, a stronger focus on anonymization of input, security aspects, or publicly available hardware installations without the need to download the app on the personal device might be needed. Despite these contextual constraints, we believe that the core findings are reproducible and provide a foundation for further research in different settings.

A second limitation concerns the study sample's social diversity. While the qualitative study aimed to include participants from diverse backgrounds, the quantitative online study relied on a relatively homogeneous sample and collected limited demographic information, restricting subgroup analyses. As a result, we cannot systematically assess how experiences of XR-based participation differ across dimensions such as migration background, accessibility needs, socio-economic status, or prior political engagement. This limitation is particularly relevant given the study's normative commitment to inclusivity and participatory parity. Future research should therefore employ more targeted sampling strategies and richer demographic data to examine where additional design adaptations may be required.

Moreover, this study did not focus on long-term participation behavior or institutional decision-making effects. Longitudinal field studies are therefore needed to assess the durability of engagement over time and the broader democratic impact of XR-based participation systems in real-world governance contexts.

Building on these findings, future research should explicitly account for contextual variation on at least two levels. First, comparative studies across countries and governance systems could examine how XR-based participation interacts with different institutional arrangements. The United Nations' biennial e-Government surveys underscore the importance of recurring cross-national comparisons, and prior work by Lee-Geiller (2020) and Zheng (2016) demonstrates how such analyses can reveal structural differences in the deployment of e-participation. Extending this line of inquiry into XR-based participation would enhance the external validity of the proposed design principles.

Second, material and infrastructural conditions require greater attention. Hardware availability, connectivity, and device familiarity vary substantially across regions, particularly in parts of the Global South where financial and infrastructural constraints may limit access to immersive technologies. Prior studies by Shahab et al. (2021) and Sari et al. (2018) have already identified significant barriers to the deployment of e-participation technologies in such contexts. Future research should therefore explore how XR-based e-participation in urban planning can be adapted to different technological ecosystems, potentially through hybrid or low-threshold configurations.

Beyond infrastructural concerns, future work should also engage more deeply with the social and political dimensions of participation. Aelbrecht and Stevens (2019) emphasize the importance of social cohesion in urban contexts, highlighting the role of public space design in fostering collective belonging. In digital government research, this raises important questions about how digital platforms—and XR-based systems in particular—can support not only e-participation, but also social integration and democratic legitimacy. Prior research has identified factors such as previous political involvement and personal interest as key drivers of e-participation (Novo Vázquez & Vicente, 2019; Rottinghaus & Escher, 2020), while gender differences in participation behavior remain underexplored (S. Kim & Lee, 2019). Investigating these factors in immersive participation settings represents a promising avenue for future research.

6. Conclusions

In times of growing societal polarization and increasing public disillusionment with political institutions (Brady & Kent, 2022), public participation is conceived not as a desirable extra but as a vital mechanism for safeguarding democratic legitimacy and social cohesion (Taylor et al., 2020). This paper therefore explored how XR-based systems can foster inclusive and motivating e-participation in urban planning, as a demanding empirical instantiation. Using the DSRIS framework and the SPP as an explicit kernel theory, we developed and evaluated an XR-based e-participation artifact across three iterative design cycles. Rather than treating participation levels as contextual background, the SPP was applied as a generative design logic that systematically informed the derivation of meta-requirements, design principles, and feature configurations across participation levels.

Taken together, this study highlights the potential of XR-based systems to move beyond the mere digitization of public participation toward more inclusive, motivating, and experientially grounded forms of democratic engagement. By aligning immersive technologies with depth of participation and institutional accountability, the proposed design principles demonstrate how e-participation can become a lived, meaningful experience rather than a symbolic exercise. At the same time, our findings underscore that technological innovation alone cannot resolve structural inequalities in participation. Issues of access, governance, and power remain central and must be addressed alongside design decisions (Pfannschmidt et al. 2026; Weinhardt et al., 2024). XR-based e-participation therefore requires not only careful system design, but also institutional safeguards that ensure transparency, inclusivity, and democratic legitimacy. We hope that the design knowledge presented in this paper provides a foundation for future research and practice at the intersection of information systems, urban planning, and digital democracy, and encourages further exploration of how immersive technologies can responsibly contribute to democratic renewal.

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Author contributions

CRediT: **Jonas Fegert:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing; **Jella Pfeiffer:** Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review & editing.

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Appendix

Table A1. Meta-requirements related to the respective questions in the quantitative study questionnaires (Second and third cycle).

MR	Topic	Item	Question	DSR Cycle
MR-1.1	Intuitive navigation (IN) (Construct "perceived ease of use" by Venkatesh and Davis 2000)	IN1	My interaction with the app was clear and understandable.	III
		IN2	Interacting with the app did not require a lot of mental effort.	
		IN3	I found the app was easy to use.	
		IN4	I found it easy to get the app to do what I wanted.	
MR-1.3	Social media connection (SM) (based on Lindner and Aichholzer, 2020)	SM	I think that connecting such an app to social media (e.g., Facebook or Instagram) would be beneficial.	III
MR-2.2; 2.4	Information detail (ID) (self-developed)	ID	I would prefer if the app offered more details about the construction project.	III
	Information urgency (IU) (self-developed)	IU	Through my use of the app I became aware of the background of this participation process/ initiative.	III
	Informativeness of the visualizations (IV) (scale was self-developed)	IV1	Using the demonstrator helped me imagine how the new enclosure would fit into the zoological garden.	II
		IV2	What do you estimate: by how much is the new enclosure larger than the old one?	II
		IV3	With the support of the demonstrator, I could easily imagine the dimensions of the new enclosure.	II
		IV4	Compared to the demonstrator, I would have preferred a miniature model of the enclosure to inform myself about the construction project of the zoological garden.	II
MR-2.1	Perceived telepresence (PT) Based on Ff-H et al., (2011); T. Kim & Biocca, (1997); Lr, (2003)	PT1	I forgot about my immediate surroundings when I was using the demonstrator.	II; III
		PT2	When using the demonstrator ended, I felt like I came back to the "real world" after a journey.	II; III
		PT3	During using demonstrator, I forgot that I was in the middle of a fair.	II
MR-3.2	Motivation to participate in the project (MP) Based on Naranjo-Zolotov et al., (2019)	MP	The demonstrator would motivate me to become more involved with the construction project.	II
MR-3.4	Willingness to donate (WD) (scale was self-developed)	WD	After using the demonstrator, I feel more willing to donate for the island for ring-tailed lemurs.	III
MR-3.5	Moderation of discussions (MD) Rosenberry, (2011)	MD1	It is important for me to know that a forum for discussions is moderated.	III
		MD2	The possibility of anonymous participation on the internet is generally important to me.	III
		MD3	It is important for me to see the name of other users instead of a username.	III
MR-5.1	Personal data and trust self-developed and based on Parycek et al., (2014)	DT	It is important for me to check the privacy measures before using such an app.	III
MR-1.5	Artifact's usefulness for further cases (AU) Based on Naranjo-Zolotov et al., (2019)	AU1	Could you possibly imagine informing yourself about other construction projects in this manner?	II
		AU2	For which other areas or construction projects could you imagine using the technology?	II

Note: IV2, AU1 and AU2 were not measured on 7-point Likert scales.

Table A2. Post-hoc comparisons across SPP levels for familiarity (Tukey HSD).

Linear Comparison	Coefficient Estimate	Confidence Interval—Lower	Confidence Interval—Upper	Standard Error	p-Value
Level 1 to Level 2	0.052	0.170	0.275	0.081	0.968
Level 1 to Level 3	0.052	0.170	0.275	0.081	0.968
Level 1 to Level 4	0.490	0.267	0.712	0.081	<0.001***
Level 1 to Level 5	0.589	0.367	0.811	0.081	<0.001***
Level 2 to Level 3	0.000	−0.222	0.222	0.081	1.0
Level 2 to Level 4	0.437	0.215	0.659	0.081	<0.001***
Level 2 to Level 5	0.537	0.314	0.759	0.081	<0.001***
Level 3 to Level 4	0.437	0.215	0.659	0.081	<0.001***
Level 3 to Level 5	0.537	0.314	0.759	0.081	<0.001***
Level 4 to Level 5	0.099	−0.123	0.322	0.081	0.739

Table A3. Post-hoc comparisons across SPP levels for confidence (Tukey HSD).

Linear Comparison	Coefficient Estimate	Confidence Interval—Lower	Confidence Interval—Upper	Standard Error	p-Value
Level 1 to Level 2	0.120	−0.109	0.350	0.084	0.606
Level 1 to Level 3	0.327	0.098	0.556	0.084	<0.001***
Level 1 to Level 4	0.791	0.561	1.020	0.084	<0.001***
Level 1 to Level 5	0.862	0.640	1.098	0.084	<0.001***
Level 2 to Level 3	0.207	−0.022	0.436	0.084	0.099
Level 2 to Level 4	0.670	0.441	0.899	0.084	<0.001***
Level 2 to Level 5	0.749	0.520	0.978	0.084	<0.001***
Level 3 to Level 4	0.463	0.234	0.692	0.084	<0.001***
Level 3 to Level 5	0.542	0.313	0.771	0.084	<0.001***
Level 4 to Level 5	0.079	−0.151	0.308	0.084	0.883

Table A4. Groups of stakeholders interviewed and their role within urban planning projects.

Stakeholder Group	Position/ Role
Public administration (6 interviewees)	Traffic planning, urban planning, green/open space planning, representatives for citizen participation, representatives for youth, social usage and supply concepts.
Planning firms (2 interviewees)	Building competition management, planning
Civil society organizations (3 interviewees)	Environmental associations, representatives for people with physiological disabilities
City council and representatives (1 interviewee)	Member of the committee for urban planning and building regulations
Construction company (1 interviewee)	Building cooperative
Technical experts (1 interviewee)	Traffic engineering and modeling in immersive environments