Urban Planning
2026 • Volume 11 • Article 12631
https://doi.org/10.17645/up.12631

ARTICLE

Open Access Journal

Embedding Virtual Reality in Urban Planning Workflows: Resource-Efficient Participation Using Existing Spatial Data

Marc Schwarzkopf, Miriam Reichert, Holger Hoffmann, and Angelika C. Bullinger-Hoffmann

Department of Mechanical Engineering, Chemnitz University of Technology, Germany

Correspondence: Marc Schwarzkopf (marc.schwarzkopf@mb.tu-chemnitz.de)

Submitted: 24 April 2026 **Accepted:** 27 August 2026 **Published:** 23 September 2026

Issue: This article is part of the issue "Citizen-Centric Urban Planning Through Participatory Sensing Data and Digital Tools" edited by Gamze Dane (Eindhoven University of Technology), Bernd Resch (Interdisciplinary Transformation University Austria), and Peter Zeile (Karlsruhe Institute of Technology), fully open access at https://doi.org/10.17645/up.i530

Abstract

Urban planning often relies on abstract representations that are difficult for non-expert citizens to interpret. This article presents a VR-supported participation approach that reuses existing urban planning data to support spatial communication, consultation, and post-implementation reviews in urban planning workflows. We conducted a stakeholder-based requirements analysis with urban planning experts ($N = 20$) to derive requirements for the approach, focusing on usability, accessibility, adaptability, and feasibility within municipal planning contexts. We then report on an exploratory case study with 99 citizens accompanying the redesign of a public basketball court and the surrounding area primarily intended for younger users, covering both pre-implementation communication and post-implementation evaluation. The findings suggest that existing CAD-derived planning data can be translated into an accessible immersive representation that participants and practitioners perceived as usable and helpful for understanding the planned intervention. At the same time, the study highlights important limits regarding realism, participation quality, and generalizability. The presented approach appears promising as a complementary tool for information provision, consultation, and reflection.

Keywords

citizen participation; digital planning tools; immersive visualization; post-implementation evaluation; urban planning; virtual reality

1. Introduction and Theoretical Framing

Citizen participation has become a central principle of contemporary urban planning and governance (Bastos et al., 2022; Dean, 2018). Planning processes are increasingly expected not only to produce technically sound spatial solutions, but also to ensure legitimacy, transparency, and responsiveness to diverse social needs (Dral et al., 2023; Nadin et al., 2021; OECD, 2022). Participatory approaches are therefore widely regarded as important for improving the contextual quality of planning outcomes, strengthening democratic decision-making, and fostering public acceptance of urban development projects (Sebunya & Gichuki, 2024; Wilson & Tewdwr-Jones, 2022).

At the same time, participation remains difficult to achieve in practice. Planning processes are often shaped by specialized professional knowledge, regulatory constraints, and limited administrative resources (Legacy, 2017; Schwarzkopf et al., 2023). Participation concepts may formally exist without necessarily becoming inclusive, influential, or substantively meaningful, particularly when they privilege actors who are already well informed, articulate, and institutionally confident (Legacy, 2017; Nochta et al., 2021). A central reason for this limitation lies in the communicative structure of planning itself: Planning proposals are typically conveyed through maps, technical drawings, renderings, or planning documents that require professional literacy to interpret (Eilola et al., 2023; Küstermann & Bittner, 2021; Wolf et al., 2020). For non-expert participants, these representations can remain abstract and difficult to translate into everyday spatial experience.

1.1. Participation, Spatial Communication, and Post-Implementation Learning

The difficulty of communicating spatial complexity is closely related to the participation paradox (Reinert & Sinning, 1997; Wolf et al., 2020). Opportunities for public influence are usually greatest in the early phases of a planning process, when design alternatives remain open and modifications can still be made with relatively limited effort. Yet public interest and engagement often remain limited at precisely this stage, because future interventions exist only as abstract plans or technical representations. Once a project becomes physically visible and easier to grasp, participation often intensifies, but by then the room for substantial change is frequently reduced.

At the heart of this paradox lies the problem of spatial imagination (Wolf et al., 2020). Citizens are expected to comment on spatial interventions before they can experience or assess their potential effects. Conventional planning representations may communicate dimensions, functions, and formal design features, but they often fail to convey how a future space might actually be perceived and used (Mansourian et al., 2011). Atmosphere, orientation, accessibility, and perceived usability are difficult to infer from plans or static renderings alone. Improving participation therefore depends not only on whether citizens are invited to engage, but also on whether planning content is communicated in a way that can be understood, assessed, and related to lived spatial experience.

A related challenge concerns learning after implementation. Participation processes often focus on communication and feedback during the design phase, while comparatively little attention is paid to whether interventions meet users' expectations once they are built (Schwarzkopf et al., 2023). Without structured post-implementation feedback, planning institutions have limited opportunities to assess whether the communicative approaches used during participation were adequate, whether expectations were met, and how future participation processes could be improved.

1.2. Immersive Visualization as an Experiential Planning Tool

Digital technologies have increasingly been discussed as possible responses to these structural challenges in participatory planning (Batty & Yang, 2022; Berigüete et al., 2024; Dane et al., 2024). Online participation platforms, interactive mapping tools, and digital visualization techniques can widen access to planning information, extend participation beyond face-to-face events, and create additional channels for feedback. However, digitalization does not automatically resolve the core problem of translating professional planning representations into forms that are appropriate for everyday spatial judgment.

Within this broader field, immersive visualization technologies such as head-mounted displays (HMDs) and VR have attracted particular attention because they can shift planning communication from abstract description toward situated experience. By enabling users to explore a planned environment from a first-person perspective, VR can provide a spatially legible reference frame for discussing design alternatives, articulating concerns, and evaluating future environments (Dane et al., 2024; van Leeuwen et al., 2018; Wolf et al., 2020). From a planning perspective, the relevance of immersive visualization therefore lies not primarily in technological novelty, but in its potential to mediate between expert planning knowledge and everyday spatial perception (Berigüete et al., 2024).

At the same time, the practical value of immersive visualization remains conditional. For VR-supported participation tools to have practical value beyond isolated demonstrations, they must be understandable for diverse user groups, feasible under routine administrative conditions, and compatible with existing data infrastructures, participation concepts, and resource constraints (Schwarzkopf et al., 2023). This is especially relevant because many existing studies emphasize technological feasibility, visualization quality, or short-term user responses, while providing less evidence on how immersive approaches can be embedded in everyday municipal planning workflows (Batty & Yang, 2022; Dane et al., 2024).

VR-supported participation should therefore be understood not as a substitute for deliberative or decision-oriented formats, but as a complementary communication layer that can make planning proposals more accessible and easier to discuss (van Leeuwen et al., 2018; Wolf et al., 2020). In this article, empowerment refers to citizens' increased capacity to understand proposals, articulate place-based concerns, and participate on a more informed basis. This communicative form of empowerment should be distinguished from stronger forms of participatory power, which require citizens to influence the development of alternatives and subsequent decisions (Arnstein, 1969; OECD, 2022). In the present framing, the boundary toward participatory co-creation is crossed when citizens can develop or modify alternatives, engage in iterative dialogue with planners, and exert a traceable influence on subsequent decisions (Dane et al., 2024). The approach examined in this study therefore remains primarily on the information and consultation side of this boundary, while potentially providing a communicative basis for more participatory formats.

1.3. Research Gap, Aim, and Contribution

Taken together, these challenges point to three research gaps that are particularly relevant for planning practice. First, there is still limited evidence on how immersive visualization can be implemented within routine municipal conditions using existing planning data and limited additional resources. Second, the institutional requirements that determine whether planners can actually adopt such tools in practice remain insufficiently understood. Third, most existing studies focus on anticipatory use during planning, while empirical evidence across different stages of the planning cycle, especially after implementation, remains scarce.

This article investigates how immersive visualization can be embedded in urban planning workflows to support spatial communication, consultation, and post-implementation reflection. The study adopts a practice-oriented perspective that links the design of digital participation tools with the institutional realities of municipal planning departments. More specifically, it examines which requirements VR-supported participation approaches must fulfill in order to be applicable in real-world planning contexts, how existing planning data can be translated into an accessible immersive representation, and how such an approach is perceived before and after implementation of a spatial intervention.

For our study, citizen participation is understood primarily as information provision, consultation, and structured feedback collection. The study does not examine deliberative co-design, co-decision, or direct influence on final planning decisions. Accordingly, the empirical evaluation focuses on perceived comprehensibility, usability, suitability, realism, and practical feasibility rather than on objective indicators of participation quality or decision-making impact.

This study is guided by three research questions:

> RQ1: Which requirements do planning practitioners identify for VR-supported participation approaches that can be integrated into routine urban planning workflows?
>
> RQ2: How can existing planning data be translated into a low-threshold VR-supported participation approach for citizen-facing planning communication?
>
> RQ3: How is the VR-supported participation approach perceived by citizens and planning practitioners before and after implementation of a spatial intervention?

By combining a stakeholder-based requirements analysis with an exploratory case study of a VR-supported participation approach in a municipal planning project, the article makes three contributions. First, it provides empirically grounded insights into practitioner requirements for integrating immersive visualization into planning workflows. Second, it shows how existing CAD-derived planning data can be translated into a low-threshold VR representation for information provision and consultation. Third, it links pre-implementation visualization with post-implementation evaluation, thereby highlighting both the potential and the limits of VR-supported representations for planning reflection and participatory learning.

2. Research Design and Methods

2.1. Overall Research Design and Scope of Participation

The study followed a sequential, practice-oriented research design linking stakeholder requirements, VR-supported tool development, citizen-facing use, and post-implementation reflection. The design was chosen because the study did not aim to evaluate VR solely as a technological prototype, but to examine how immersive visualization can be embedded in routine urban planning workflows under practical administrative conditions. Compared with a conventional workflow in which existing planning data are translated into static presentation materials, the proposed workflow adds an immersive adaptation step, structured HMD-based consultation, and post-implementation reflection while retaining existing municipal planning data as its primary basis. The research process consisted of five connected steps (Figure 1).

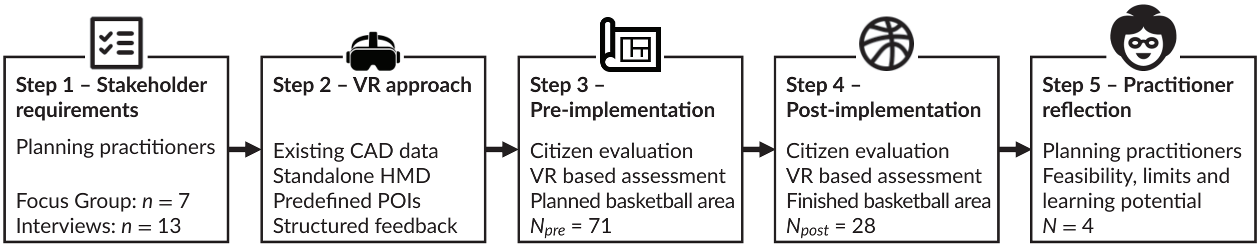


Figure 1. Proposed VR-supported planning and participation workflow and sample sizes across the empirical phases (POI = point of interest).

2.2. Stakeholder-Based Requirements Analysis

The first empirical phase consisted of a stakeholder-based requirements analysis involving $N = 20$ experts with professional experience in urban planning and citizen participation. Participants were recruited through purposive sampling from municipal planning departments, participation coordination, mobility planning, and related communication or implementation roles. This stakeholder group was selected because these practitioners are directly involved in organizing participation processes, communicating planning proposals to citizens, and translating administrative requirements into practical planning procedures.

The requirements analysis combined an exploratory focus group workshop with semi-structured expert interviews. As an initial step, a focus group workshop was conducted with seven experts from urban planning, mobility planning, and participatory planning practice. The workshop was adapted from Zimmermann et al. (2009) and aimed to identify challenges in citizen participation, explore the perceived value of immersive visualization, and derive preliminary requirements for VR-supported participation approaches in urban planning (Schwarzkopf et al., 2023). It was organized as a structured six-phase format (Figure 2).

To complement the focus group results and broaden the empirical base, 13 additional semi-structured expert interviews were conducted. The interviews lasted between one and two hours and followed a guide aligned with the workshop themes. They addressed current participation practices, goals and expectations of citizen involvement, evaluation of implemented projects, existing tools and methods, communication challenges, requirements for digital support tools, and opportunities and limitations of VR-based visualization.

The qualitative data from the workshop and interviews were analyzed using qualitative content analysis following Kuckartz (2012). All available records, notes, and interview materials were reviewed and transcribed. Two researchers initially reviewed and coded the material independently to identify recurring themes related to participation challenges, communicative barriers, digital support needs, and institutional constraints. Coding differences were discussed and resolved through consensus. No formal intercoder

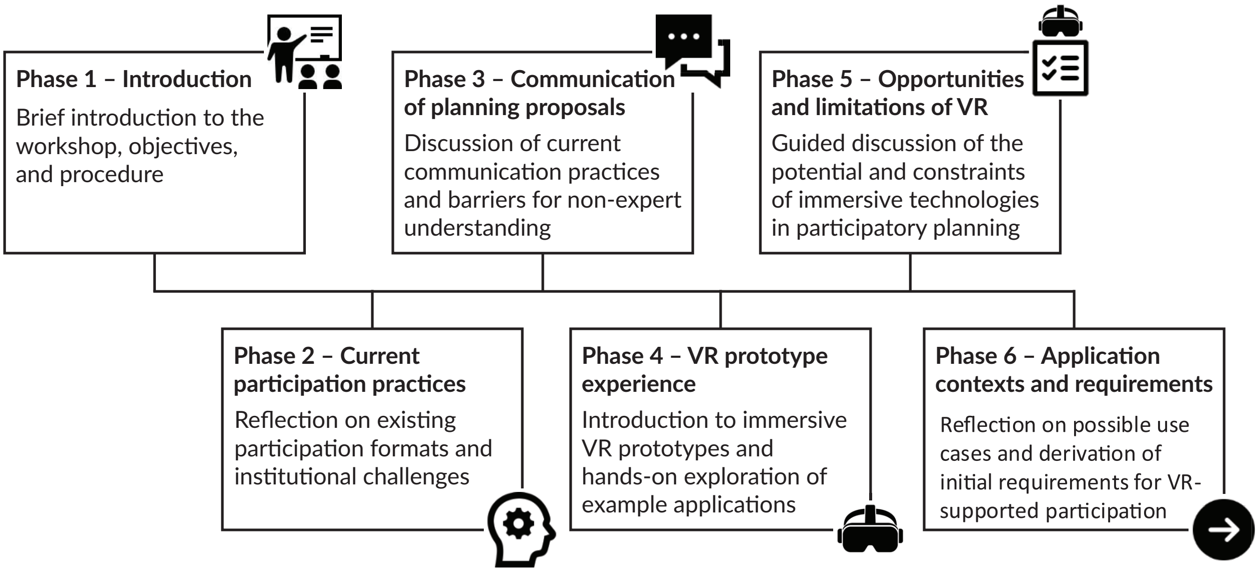


Figure 2. Six-phase structure of the exploratory focus group workshop.

reliability coefficient was calculated because the analysis was exploratory and aimed to derive practice-oriented requirements. The codes were then grouped into broader categories and translated into requirement areas. Across the data, five overarching requirement areas emerged: *usability and accessibility*, *visualization of planning proposals*, *participation and feedback mechanisms*, *data analysis*, and *integration into planning workflows*. These categories were consolidated into core participation functions and implementation-related requirements that informed the design of the VR-supported participation approach. To increase transparency, the results section includes illustrative quotes from the qualitative material to show how selected practitioner concerns were translated into design-relevant requirements.

2.3. Design and Instantiation of the VR-Supported Participation Approach

Based on the stakeholder requirements, a VR-supported participation approach was developed to support communication, feedback, and evaluation in urban planning processes. The approach was designed as a complementary layer within existing participation concepts rather than as a replacement for established planning procedures. Its purpose was to make the spatial implications of planning proposals easier to understand for citizens while remaining feasible under routine administrative conditions.

The approach translated the stakeholder requirements into several design decisions. First, existing CAD-derived planning data were used as the primary data source in order to reduce additional modeling effort and improve compatibility with planning workflows. Second, the system was implemented on a standalone HMD (PICO 4 Enterprise) to allow flexible deployment during citizen-facing participation activities without requiring additional computing equipment. Third, interaction was intentionally simplified through five predefined points of interest (POIs), allowing participants to experience the planned intervention from standardized spatial perspectives. Fourth, structured feedback was collected after the VR experience using questionnaires, enabling results to be documented and analyzed for subsequent planning reflection.

The VR application was implemented using the Unity game engine and was based on CAD-derived spatial planning data representing the proposed redesign of the basketball court and surrounding area (Figure 3). These data were provided by the municipal green space department and had originally been created for spatial calculation and planning purposes rather than for citizen participation. For the present study, they were translated into an immersive environment suitable for public engagement. In addition, five stereoscopic 360-degree photographs of the park in its pre-intervention condition were integrated into the procedure to provide participants with a standardized reference to the existing site. The intervention covered an area of approximately 7,500 m² and also included the redesign of surrounding green space. The construction phase lasted approximately 12 months.

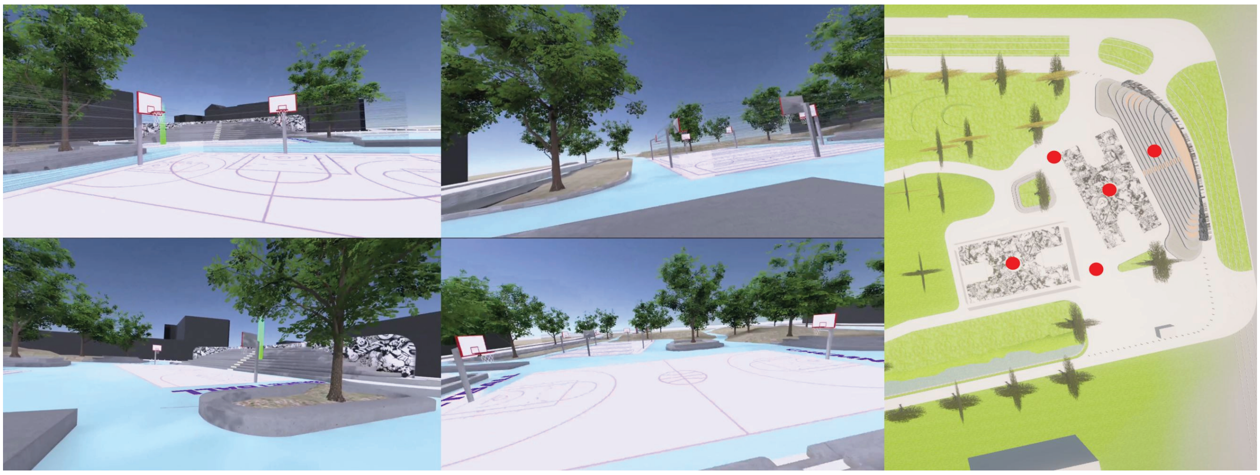


Figure 3. Impressions from the VR environment. Notes: The right panel shows a bird's-eye view of the VR model; red dots mark the five POIs.

In this article, "resource efficiency" means making use of planning data and hardware that are already available to keep the additional preparation effort low. The approach was based mainly on existing CAD planning data, a standalone HMD, and only limited adjustments to the model. Around four additional hours of work were needed to add simplified contextual elements, prepare the VR scenes, and integrate the 360-degree photographs. The approach is therefore not cost-free, but requires comparatively little additional preparation. In practice, it required one standalone HMD, a Unity-based application, basic skills in preparing and adapting 3D planning data, and one facilitator during the participation activities. Maintenance was mainly limited to updating or adapting the visualization when the planning data changed.

2.4. Exploratory Case Study and VR Procedure

The VR-supported participation approach was applied in an exploratory case study in Chemnitz, Germany. The case focused on the redesign of a basketball court and surrounding area located in a public park. The planning objective was to improve the spatial layout, accessibility, and usability of the facility, particularly for children, teenagers, people with disabilities, and other park users, while integrating the sports area more effectively into the surrounding park environment.

The case study consisted of two empirical phases separated by approximately 20 months. The pre-implementation phase examined how citizens perceived the proposed redesign when presented through immersive VR visualization before construction. The post-implementation phase evaluated the completed site and compared citizens' perceptions of the completed site with the earlier virtual representation. Because the two phases were based on different groups, the comparison should be interpreted as an exploratory two-phase comparison rather than as evidence of individual change over time.

The pre-implementation sample consisted of N_{pre} = 71 participants and had a mean age of 25.76 years (*SD* = 11.10; range = 9–81 years). Participants were recruited both on-site and at a participation event held prior to a basketball game in a local exhibition hall. The post-implementation sample consisted of N_{post} = 28 participants with a mean age of 28.32 years (*SD* = 12.15; range = 10–44 years), who were recruited on site after completion of the intervention. Descriptively, the mean ages of the two samples were similar, although the samples were recruited independently and were not matched at the individual level.

Participation was voluntary in both phases, and all participants received a short standardized introduction to the procedure and the VR system before use. The VR procedure followed a standardized sequence. Participants first viewed five stereoscopic 360-degree photographs of the park in its pre-intervention condition before entering the VR model of the proposed redesign. During the VR phase, they explored the virtual environment for approximately five minutes while standing. The environment included predefined POIs that were presented in a fixed order to ensure that all participants were exposed to comparable spatial perspectives. At each viewpoint, participants could look around freely, but free movement through the model was not possible. Navigation between viewpoints was controlled by the participants via a simplified interaction interface and supported by the experimenter when necessary. This simplified interaction design was chosen to minimize operational complexity, avoid orientation problems, and balance user-directed exploration with practical usability in a public participation setting (Kaur et al., 2020). After the VR experience, participants completed a structured questionnaire via tablet.

2.5. Participation Functions and Practical Feasibility

The VR-supported approach was designed to fulfill three core functions within the participation process. First, it supported information provision by making the spatial characteristics of the planned intervention easier to understand. Second, it supported consultation by providing a concrete visual basis on which participants could formulate feedback. Third, it supported post-implementation evaluation by allowing the planned representation to be revisited and compared with the completed site after implementation.

The approach therefore functioned as a communicative interface linking planning intentions, structured citizen feedback, and post-implementation reflection. Its practical feasibility was supported by several design choices described above, including standalone deployment in parks, public buildings, exhibition spaces, and other non-specialized settings, the reuse of existing planning data, predefined viewpoints, and simplified interaction. Together, these features were intended to facilitate implementation in diverse citizen-facing contexts and under routine administrative conditions.

2.6. Measures and Data Analysis

The citizen questionnaires consisted mainly of short, study-specific items designed for use in public participation settings. The pre-implementation questionnaire assessed perceived practicality of hardware, the usefulness of the 360-degree photographs for understanding the existing site, the suitability of the VR environment for evaluating the redesign, ease of use, and VR-related discomfort or motion sickness. At one pre-implementation participation event, $N_{pref} = 45$ participants were additionally asked to indicate which of four available presentation modalities they preferred for communicating the planned intervention: a conventional PowerPoint-based presentation, self-directed exploration using an HMD, presentation of the VR simulation on a large screen, or a video of a 3D rendering of the basketball court and surrounding area. Participants selected one preferred modality. The item was analyzed descriptively.

The post-implementation questionnaire assessed the attractiveness of the realized intervention, perceived practicality of the hardware, suitability of the VR environment, ease of use, perceived realism, presence, usefulness, satisfaction, future intention to use the approach again, affinity for technology interaction (Franke et al., 2019), and perceived discrepancies between VR and the realized environment. Perceived realism was assessed through three dimensions: overall realism, spatial realism, and design realism.

Several constructs were assessed using single-item or study-specific measures to keep the questionnaire short and feasible during public participation activities. The items were therefore not intended to provide a fully validated measurement model, but to capture participants' immediate evaluation of the VR-supported participation approach in an applied field setting.

Quantitative data were analyzed descriptively using means and standard deviations. For the post-implementation phase, Spearman's rho correlations were calculated to explore associations between presence, ease of use, usefulness, satisfaction, future intention to use, and perceived realism. Differences between the independent pre- and post-implementation samples were examined using two-sided Mann-Whitney U tests, with $r = \frac{|Z|}{\sqrt{N}}$ reported as the effect size. The participants could directly compare the VR representation with the completed site. Given the independent samples, the comparatively small post-implementation sample, and the exploratory design, the results were interpreted cautiously.

Open-ended responses on perceived discrepancies between the VR representation and the completed site were categorized descriptively. The categories were used to identify whether participants perceived deviations as problematic and which aspects of the model were considered less convincing, such as vegetation, seating elements, orientation cues, or environmental detail.

2.7. Ethics and Data Protection

Before using the HMD, participants received a short safety briefing and were informed that they could stop the VR experience at any time in case of discomfort. Potential VR-related discomfort was monitored throughout all sessions. The study was approved by the ethics committee of the university (approval no. 101579653). Participation in all empirical phases was voluntary and based on informed consent. Participants were informed about the purpose of the study, the procedure, the use of the collected data, and their right to withdraw at any time. Minors were included only if accompanied by a responsible adult during participation. No directly identifying personal data were stored together with the survey responses, and all data were analyzed in anonymized form.

3. Results

3.1. Stakeholder-Based Requirements

To make the derivation of requirements more transparent, Table 1 provides illustrative examples from the qualitative material. The table does not present the full coding scheme, but shows how selected practitioner concerns from the focus group and interviews were translated into design-relevant requirements for the VR-supported participation approach. Quotes were anonymized and translated into English by the authors.

Table 1. Illustrative qualitative evidence for selected requirement areas derived from the stakeholder analysis.

Category	Illustrative quote	Derived requirement	Implementation response
Usability and accessibility	It depends on how quickly people understand the system, particularly children, people with impairments, and older people. But many adults, too, do not have the patience to spend much time going through instructions.	Provide low-threshold interaction and optional facilitation.	Standalone HMD, simplified controls, predefined viewpoints, and facilitator support when needed.
Visualization of planning proposals	Even we, as planners, sometimes find it difficult to understand planning maps. As for members of the public, who are expected to understand and visualize such things: They don't stand a chance. That is why we try to rely on 2D renderings, although these often fail to convey a sense of space and are depicted from unusual angles.	Provide an intuitive spatial representation of the planned intervention.	Immersive VR environment based on existing CAD-derived planning data.
Integration into planning workflows	We are very constrained by regulatory requirements; we have neither the financial nor the time resources to carry out experiments. That is why the support provided must be tailored to me as the planner.	Reuse existing planning data and minimize additional preparation effort.	CAD-based model preparation, lightweight contextual adaptation, and standalone deployment.

The stakeholder analysis resulted in a set of core participation functions (Table 2) and implementation and usability requirements (Table 3) that define the conditions under which immersive visualization can be integrated into participatory urban planning practice. Overall, the findings show that planning practitioners do not primarily evaluate VR as a technological novelty, but as a potential support tool whose value depends on whether it can reduce communication barriers, facilitate citizen feedback, and fit routine administrative conditions. Taken together, the results show that the requirements for immersive participation approaches are shaped by a dual expectation. On the one hand, such approaches are expected to enhance the communicative quality of participation by making planning proposals more spatially legible, intuitive, and easier to discuss for citizens. On the other hand, they must remain institutionally feasible, which means they have to align with existing data infrastructures, administrative capacities, and participation routines.

This duality is central to the contribution of the stakeholder analysis. It suggests that the relevance of immersive visualization in urban planning does not depend primarily on technological sophistication or photorealistic representation, but on whether the tool can function as a workable interface between professional planning knowledge and citizen understanding. In this sense, the requirements analysis provides the conceptual bridge between planning theory and tool development: It translates abstract demands for more inclusive and comprehensible participation into empirically grounded design criteria for immersive planning support. These findings provide the empirical basis for the design decisions described in Section 2.3.

Table 2. Core participation functions derived from the stakeholder analysis and their implementation in the VR-supported participation approach.

Core participation functions	Design feature	Implementation
Immersive spatial visualization	VR-based 3D environment	Planning proposals are visualized in an immersive virtual environment using HMDs.
Contextual spatial information	Integration of CAD planning data	Existing spatial planning data and surrounding environmental elements are integrated into the VR environment.
Scenario comparison	Multiple VR scenes	Different planning stages or alternative designs can be presented as separate VR scenes.
Structured participation	Guided exploration sequence	The VR system guides participants through a structured sequence of viewpoints during the experience.
Feedback collection	Post-experience questionnaire	Participants provide structured feedback after exploring the VR environment. The questionnaires should be easy to adapt.
Documentation of participation feedback	Digital data collection	Citizen feedback is stored digitally and can be analyzed in subsequent planning steps.

Table 3. Implementation and usability requirements derived from the stakeholder analysis and their implementation in the VR-supported participation approach.

Implementation and usability requirements	Design Feature	Implementation
Intuitive usability	Simplified interaction design	Interaction is limited to basic viewing and scenario switching to ensure ease of use.
Low entry barriers	Standalone VR headset deployment	The system runs on standalone HMDs without requiring external computers.
Accessibility and inclusiveness	Facilitated VR usage option	Participants can explore the VR environment independently or with assistance from facilitators.
Technical reliability	Stable system deployment	The application is designed to run reliably during participation events.
Integration with planning workflows	Use of existing planning data	The VR environment is generated using spatial data already available in planning processes.
Efficient evaluation support	Structured digital feedback output	Collected participation data can be exported and analyzed within planning workflows.
Easy to maintain by planners	Provide easily adaptable content and scenarios	Content (especially visualization data) must be easily and quickly exchangeable.

3.2. Pre-Implementation Evaluation

Overall, the usability, hardware practicality, and task suitability were rated positively (Table 4).

Table 4. Ratings of the pre-implementation group (N = 71), 6-point Likert scale, from 1 (*very good*) to 6 (*insufficient*).

Item	*M* (*SD*)
How do you rate the practicality of the hardware used for the presentation of the proposed design?	1.50 (.60)
How well were you able to assess the current state of the park with the help of the 360° images?	1.67 (.72)
How suitable is the virtual environment for evaluating the redesign of the park?	1.33 (.69)
How do you rate the ease of use of the technology?	1.29 (.51)

At one of the pre-implementation participation events, N_{pref} = 45 participants also indicated their preferred presentation modality. Self-directed exploration using an HMD was selected most frequently (n = 20, 44.4%), followed by a conventional PowerPoint-based presentation with 2D renderings (n = 14, 31.1%), a video of a 3D rendering of the basketball area (n = 7, 15.6%), and presentation of the VR simulation on a large screen (n = 4, 8.9%). These descriptive findings indicate a comparatively high preference for direct HMD-based exploration. However, the item assessed subjective preference rather than differences in comprehension, feedback quality, or participation outcomes. Across all pre-implementation participation events, no participant reported symptoms suggestive of motion sickness.

Together, these findings suggest that the tool was perceived as helpful for communicating planning content in an accessible and user-friendly way, even though the model itself was based on relatively simple planning data rather than on a highly elaborate or photorealistic simulation.

3.3. Post-Implementation Evaluation

Based on the post-implementation sample, participants evaluated the redesigned basketball court and surrounding area positively. The attractiveness of the realized intervention was rated highly (M = 1.72, SD = 0.55), indicating that the implemented design was generally well received by users. At the same time, the evaluation showed that the post-implementation assessment was not limited to judgments of the built space alone, but also captured participants' experience of the VR tool under more demanding comparison conditions. Despite the possibility to compare the VR representation with the completed site, all indicators of VR acceptance remained in the positive range (Table 5).

The realism of the model was assessed quantitatively through three dimensions: overall realism, spatial realism, and design realism. As summarized in Table 5, the corresponding values indicate a moderate but clearly positive evaluation of the model's realism.

Overall realism reached a moderate value of M = 2.51 (SD = 0.85), suggesting that participants regarded the simulation as sufficiently realistic to support orientation and evaluation, but not as a fully equivalent substitute for the physical environment. Given the simplicity of the model and the technical origin of the underlying

Table 5. Ratings of the post-implementation group ($N = 28$) on six-point rating scales; lower values indicate more positive evaluations.

Item	*M* (*SD*)
How do you rate the practicality of the hardware used for the presentation of the proposed design?	1.43 (.69)
How suitable is the virtual environment for evaluating the redesign of the park?	1.79 (.79)
How do you rate the ease of use of the technology?	1.64 (.73)
Overall realism—overall similarity to reality	2.51 (.85)
Spatial realism—realism of spatial layout	2.36 (.90)
Design realism—realism of aesthetic design	2.26 (.87)

planning data, this moderate realism rating is noteworthy. In this sense, the moderate realism rating indicates that even comparatively rudimentary planning data can be translated into a representation that users perceive as sufficiently plausible for participatory purposes.

3.3.1. Post-Implementation Evaluation: Perceived Discrepancies Between VR and Reality

To examine whether participants considered specific discrepancies between the VR simulation and the realized intervention problematic, an open-ended question was included asking whether aspects of the VR model had been represented differently from how they appeared in reality and, if so, which aspects. The responses indicate that such discrepancies were only perceived as problematic by a minority of participants (Table 6). A clear majority ($n = 23$) reported no relevant problems and described the simulation as sufficiently representative of the essential features of the redesign.

Table 6. Open-ended comments on perceived discrepancies between VR and the realized environment.

Category	*n*	Example/paraphrase
No relevant discrepancy perceived	23	Simulation sufficiently represented the main elements
Specific element mismatch	5	Vegetation, grandstand, seating, and table tennis elements
Orientation context	1	Surrounding buildings would have supported orientation
Artificial visual style	1	Model appeared somewhat comic-like
Implemented differently than expected	1	Certain elements shown in VR were not implemented

Note: Responses could refer to more than one type of discrepancy.

Several respondents explicitly emphasized that the VR model successfully conveyed the core structure and overall design logic of the intervention, even if not every detail was reproduced exactly. In this sense, the simulation was often interpreted as a conceptual preview rather than a photorealistic reproduction. Some participants even argued that a stronger focus on detail would have been counterproductive, as it might have distracted from the key spatial features relevant for evaluating the design.

Overall, the pattern of responses suggests that most participants accepted a certain degree of abstraction in the VR model as appropriate for participatory purposes. The fact that only a small minority perceived deviations as problematic supports the interpretation that the model was largely successful in communicating the main spatial and functional characteristics of the redesign. At the same time, the responses indicate that detail-related discrepancies become particularly salient when they affect orientation, aesthetic expectations, or specific functional elements.

3.3.2. Post-Implementation Evaluation: Relationships Between Presence, Usefulness, Ease of Use, and Future Intention

To examine the acceptance mechanisms underlying the post-implementation evaluation, correlations between the main constructs were calculated. Table 7 summarizes the relevant results. The findings are broadly consistent with previous findings of technology acceptance research (Bertrand & Bouchard, 2008), but should be interpreted as exploratory associations rather than as evidence of a validated acceptance model. Most notably, perceived usefulness was strongly associated with future willingness to use the tool again (future intention, $r_s = .601$), and ease of use was positively related to both usefulness ($r_s = .547$) and future intention ($r_s = .444$). These findings indicate that the tool was more likely to be accepted when participants perceived it as both intuitive and genuinely helpful for understanding the planning proposal.

Table 7. Spearman's rho correlation coefficients ($N = 28$).

Variable	*M*	*SD*	1	2	3	4	5	6
1. Presence	1.96	0.79	—					
2. Ease of Use	1.64	0.73	.539**	—				
3. Usefulness	1.89	0.69	.773**	.547**	—			
4. Satisfaction	2.00	0.72	.557**	.229	.434*	—		
5. Future intention	1.71	0.71	.483**	.444*	.601**	.360	—	
6. Realism (Overall)	2.51	0.85	.577**	.203	.475*	.531**	.492**	—

Notes: * $p < .05$, ** $p < .01$ (two-sided).

A particularly strong association was observed for presence. The correlation between spatial presence and perceived usefulness was the strongest observed relationship in the dataset ($r_s = .773$). The strong association indicates that higher spatial presence was closely related to higher perceived usefulness. Presence was also positively related to overall realism ($r_s = .577$), while realism itself showed a positive association with usefulness ($r_s = .475$) and future willingness to use the tool ($r_s = .492$). Together, these findings suggest that acceptance was associated not only with technical usability, but also with sense of being spatially situated within the environment.

No statistically significant associations were detected between technology affinity and perceived ease of use ($r_s = .194$, $p = .23$), usefulness ($r_s = .163$, $p = .29$), or satisfaction ($r_s = .166$, $p = .24$). Given the small sample, these findings should not be interpreted as evidence that technology affinity is irrelevant.

3.4. Comparison of Pre- and Post-Implementation Evaluations

The post-implementation sample evaluated both dimensions more critically than the pre-implementation sample. Perceived suitability differed significantly between the two groups ($U = 529.5$, $Z = -3.85$, $p < .001$, $r = .39$). Ease of use also differed significantly ($U = 619.0$, $Z = -3.60$, $p < .001$, $r = .36$). Both differences corresponded to medium-sized effects. However, because the pre- and post-implementation phases involved independent samples recruited in different settings, these findings should be interpreted as exploratory group differences rather than as individual change over time. Overall, acceptance of the procedure remained positive, while the post-implementation sample evaluated the tool more critically.

3.5. Planners' Assessment of the Final Tool in Citizen-Facing Use

In addition to the citizen-based evaluations, the final tool was also used and informally tested in direct citizen-facing settings by four planning practitioners. Although exploratory, this assessment adds an institutional perspective to the citizen data. Planners reported that the tool attracted considerable attention and appeared to encourage engagement during the participation activities. They also observed that many participants required little additional explanation, which they interpreted as an indication that the immersive representation conveyed the core spatial logic of the redesign. Finally, planners described the deployment and handling of the technology as comparatively simple, which is consistent with the broader argument that the approach is not only acceptable to citizens but also feasible within routine participation settings.

4. Discussion

This article examined how immersive visualization can be integrated into urban planning workflows to support citizen participation before and after the implementation of a spatial intervention. As an exploratory study based on a single empirical case, the findings should be understood as initial evidence rather than as broadly generalizable conclusions. Within these limits, the results suggest that VR based on existing CAD data can function as a practical, low-threshold participation tool, while also revealing important limitations regarding experiential realism and the interpretation of post-implementation comparisons.

With regard to RQ1, the stakeholder analysis showed that planning practitioners require VR-supported participation tools to be easy to use, technically stable, compatible with existing data, and manageable within limited administrative resources. The developed approach addressed these requirements through standalone deployment, simplified interaction, predefined viewpoints, and the reuse of existing planning data. This shifts the evaluation of immersive tools away from technological novelty alone and toward institutional feasibility: Their practical relevance depends on whether they can be integrated into existing administrative routines, participation formats, and resource constraints. The exploratory feedback from the four planning practitioners was consistent with this interpretation, as they perceived the tool as manageable for citizen participation.

With regard to RQ2, the findings indicate that existing CAD-derived planning data can be translated into a usable immersive representation through limited contextual adaptation and a simplified interaction design. The model was prepared within only a few additional hours of work, suggesting that immersive participation tools can be integrated into planning workflows without major new infrastructure. This does not mean that the approach is cost-free or technically trivial; its practical value lies in reducing additional preparation effort by reusing existing data. Moreover, usefulness for participation contexts did not appear to depend on photorealistic modeling, as even the comparatively simple model provided a sufficiently concrete reference for discussing the planned intervention, provided that its representational limitations were communicated transparently.

With regard to RQ3, the pre- and post-implementation evaluations suggest that the VR-supported approach was perceived positively overall, although its limitations became more visible once participants could compare the simulation with the realized intervention. In the pre-implementation phase, participants evaluated the tool as usable, practical, and suitable for assessing the planned redesign. A supplementary preference item also showed that self-directed HMD exploration was the most frequently selected presentation modality. However, this item measured subjective preference and did not test comparative effectiveness in terms of understanding, feedback quality, or participation outcomes. In the post-implementation phase, acceptance remained positive, but evaluations became more differentiated. The model was perceived as particularly helpful for understanding the general layout and functional aspects of the redesign, whereas limitations were more apparent with regard to atmosphere, orientation cues, and environmental detail.

The post-implementation phase therefore qualifies the interpretation of the approach. Immersive visualization should not be understood as a predictive reproduction of future spatial experience, but as a tool for anticipatory communication and early evaluation. It can support spatial understanding and dialogue, but cannot fully convey the multisensory, atmospheric, and contextual qualities of the built environment.

Immersive visualization may be particularly helpful for people who are unfamiliar with conventional planning representations or formal participation procedures, including children, older adults, people with impairments, and those with limited planning literacy, as first-person views can make spatial dimensions, accessibility, visibility, and intended uses easier to understand and discuss. This may help planners identify anticipated barriers, conflicts, and unmet needs. In projects concerning public space, recreation, active mobility, or accessibility, it may also bring health-related qualities such as opportunities for active use, perceived safety, accessibility, and social usability into planning discussions at an earlier stage. It is important to note that VR cannot overcome barriers such as selective recruitment, language, digital accessibility, limited trust, or unequal decision-making power by itself. Its potential also depends on facilitated use and the availability of alternative formats for people who cannot or do not wish to use an HMD. As the present study did not compare specific user groups or directly assess health-related outcomes, these implications represent planning potentials rather than demonstrated effects. In the terminology adopted in this article, these benefits may support communicative empowerment by enabling citizens to form and articulate more informed spatial judgments. However, the present approach does not demonstrate procedural empowerment or co-creation, as participants neither developed planning alternatives nor exerted traceable influence on subsequent decisions.

Linking pre-implementation participation with post-implementation reflection generated three forms of learning. First, representational learning revealed which characteristics of the model provided a plausible basis for evaluation and where experiential limitations remained. Second, practical learning showed that existing planning data could be translated into a usable participation format with limited additional effort. Third, methodological learning indicated how post-implementation evaluation can help calibrate expectations regarding realism and improve future representations. However, the study did not measure institutional learning as an organizational outcome; this remains a task for future research.

Several limitations should be acknowledged. The study examined a single recreational intervention of limited spatial scale, and the pre- and post-implementation phases involved different samples. Their comparison should therefore be interpreted as an exploratory comparison between groups rather than as individual change over time. In addition, the model deliberately prioritized ease of implementation over photorealistic detail. While this design choice was appropriate for the study aim, it limits conclusions about how different levels of graphical fidelity might affect perceived realism, usability, or feedback quality. A further limitation concerns measurement validity. Several constructs were assessed using brief, study-specific measures to keep the surveys feasible in applied public settings. Their reliability and construct validity could therefore not be comprehensively evaluated. The reported relationships between presence, usefulness, ease of use, realism, satisfaction, and future intention should consequently be interpreted as exploratory associations rather than as evidence of a validated structural model of technology acceptance.

Finally, the study does not provide direct evidence of participation quality in a substantive planning sense. It did not objectively assess whether citizen feedback became more specific, whether understanding measurably improved, or whether planning decisions were influenced by the VR-supported participation. The findings therefore support more limited conclusions: The approach was perceived as usable, understandable, and practically feasible in this case, and it provided an experiential reference that participants and planners regarded as helpful for communication, consultation, and reflection.

Future research should examine whether similar patterns emerge in larger and more complex planning contexts, particularly in fields such as transport planning, where different stakeholder constellations, conflict structures, and spatial dynamics may place different demands on immersive participation tools. It would also be valuable to investigate how different levels of visual fidelity affect citizens' understanding, expectations, and feedback, how specific user groups experience immersive participation formats, and how post-implementation evaluations can be systematically integrated into municipal learning processes.

5. Conclusion

This study examined how VR-supported participation can be integrated into urban planning workflows by reusing existing planning data. The findings suggest that a practice-oriented approach combining standalone hardware, simplified interaction, and limited adaptation of existing planning data can provide a feasible communication layer for information provision, consultation, and post-implementation reflection.

Participants and practitioners perceived the approach as usable and helpful for understanding the general layout and functional aspects of the redesign, while the comparison with the realized environment revealed limitations regarding atmosphere, contextual detail, and experiential realism. VR should therefore be understood as a complementary communication and reflection tool rather than as a substitute for deliberative participation or direct experience of the built environment.

When embedded in accessible and decision-responsive participation processes, such approaches may help planners incorporate a broader range of everyday spatial experiences into the development of inclusive and health-supportive public spaces.

Acknowledgments

The authors thank the City of Chemnitz for its cooperation and support in conducting the study. They also gratefully acknowledge the funding provided by the German Federal Ministry of Research, Technology and Space (BMFTR).

Funding

This research was funded by the German Federal Ministry of Education and Research (BMBF) through the project NUMIC 2.0 (grant no. 01UR2204B). The funder had no role in the study design, data collection, analysis, interpretation, manuscript preparation, or publication decision.

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data supporting the findings of this study will be made available via the TU Chemnitz Cloud repository: https://tuc.cloud/index.php/s/iZj4yg59FWnt3ej

LLMs Disclosure

Artificial intelligence-based tools were used to support language-related tasks during the preparation of this manuscript, specifically for translating text between German and English and for stylistic editing and shortening of existing content. The AI tools were not used to generate original scientific content, data, analyses, or interpretations. All scientific arguments, results, and conclusions were developed and verified by the authors.

References

Arnstein, S. R. (1969). A ladder of citizen participation. *Journal of the American Institute of Planners*, *35*(4), 216–224. https://doi.org/10.1080/01944366908977225

Bastos, D., Fernández-Caballero, A., Pereira, A., & Rocha, N. P. (2022). Smart city applications to promote citizen participation in city management and governance: A systematic review. *Informatics*, *9*(4), Article 89. https://doi.org/10.3390/informatics9040089

Batty, M., & Yang, W. (2022). *A digital future for planning: Spatial planning reimagined*. Digital Task Force for Planning.

Berigüete, F. E., Santos, J. S., & Rodriguez Cantalapiedra, I. (2024). Digital revolution: Emerging technologies for enhancing citizen engagement in urban and environmental management. *Land*, *13*(11), Article 1921. https://doi.org/10.3390/land13111921

Bertrand, M., & Bouchard, S. (2008). Applying the technology acceptance model to VR with people who are favorable to its use. *Journal of CyberTherapy & Rehabilitation*, *1*(2), 200–207.

Dane, G., Evers, S., van den Berg, P., Klippel, A., Verduijn, T., Wallgrün, J. O., & Arentze, T. (2024). Experiencing the future: Evaluating a new framework for the participatory co-design of healthy public spaces using immersive virtual reality. *Computers, Environment and Urban Systems*, *114*, Article 102194. https://doi.org/10.1016/j.compenvurbsys.2024.102194

Dean, R. (2018). Counter-governance: Citizen participation beyond collaboration. *Politics and Governance*, *6*(1), 180–188. https://doi.org/10.17645/pag.v6i1.1221

Dral, G. J., Witte, P. A., & Hartmann, T. (2023). The impact of participatory decision-making on legitimacy in planning: Dilemmas and tensions in the Dutch municipal planning context. *disP—The Planning Review*, *59*(1), 98–113. https://doi.org/10.1080/02513625.2023.2229633

Eilola, S., Jaalama, K., Kangassalo, P., Nummi, P., Staffans, A., & Fagerholm, N. (2023). 3D visualisations for communicative urban and landscape planning: What systematic mapping of academic literature can tell us of their potential? *Landscape and Urban Planning*, *234*, Article 104716. https://doi.org/10.1016/j.landurbplan.2023.104716

Franke, T., Attig, C., & Wessel, D. (2019). A personal resource for technology interaction: Development and validation of the affinity for technology interaction (ATI) scale. *International Journal of Human–Computer Interaction*, *35*(6), 456–467. https://doi.org/10.1080/10447318.2018.1456150

Kaur, A., Agrawal, M., & Yammiyavar, P. G. (2020). A cognitive load assessment study of three-dimensional interactive virtual reality interfaces. *International Journal of Forensic Engineering and Management*, *1*(1), 103–115. https://doi.org/10.1504/IJFEM.2020.109203

Kuckartz, U. (2012). *Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung*. Beltz Juventa.

Küstermann, G. C., & Bittner, E. A. C. (2021). Developing a GIS-integrated tool to obtain citizens' input in on-site participation: Learnings from participatory urban planning of a large city. In *Proceedings of the 54th Hawaii international conference on system sciences* (pp. 2368–2377). https://doi.org/10.24251/HICSS.2021.289

Legacy, C. (2017). Is there a crisis of participatory planning? *Planning Theory*, *16*(4), 425–442. https://doi.org/10.1177/1473095216667433

Mansourian, A., Taleai, M., & Fasihi, A. (2011). A web-based spatial decision support system to enhance public participation in urban planning processes. *Journal of Spatial Science*, *56*(2), 269–287. https://doi.org/10.1080/14498596.2011.623347

Nadin, V., Stead, D., Dąbrowski, M., & Fernandez-Maldonado, A. M. (2021). Integrated, adaptive and participatory spatial planning: Trends across Europe. *Regional Studies*, *55*(5), 791–803. https://doi.org/10.1080/00343404.2020.1817363

Nochta, T., Wahby, N., & Schooling, J. M. (2021). Knowledge politics in the smart city: A case study of strategic urban planning in Cambridge, UK. *Data & Policy*, *3*, Article 31. https://doi.org/10.1017/dap.2021.28

OECD. (2022). *OECD guidelines for citizen participation processes*. https://doi.org/10.1787/f765caf6-en

Reinert, A., & Sinning, H. (1997). Mobilisierung der Kompetenz der Bürgerinnen und Bürger: Das Bürgergutachten ÜSTRA zum öffentlichen Nahverkehr in Hannover. In T. Bühler (Ed.), *Bürgerbeteiligung und Demokratie vor Ort* (pp. 143–152). Stiftung Mitarbeit.

Schwarzkopf, M., Dettmann, A., Heinz, A., Miethe, M., Hoffmann, H., & Bullinger, A. C. (2023). Let's use VR! A focus group study on challenges and opportunities for citizen participation in traffic planning. In H. Krömker (Ed.), *HCI in mobility, transport, and automotive systems* (pp. 358–371). Springer. https://doi.org/10.1007/978-3-031-35678-0_24

Sebunya, J., & Gichuki, A. (2024). The impact of participatory planning on sustainable development: A literature review. *Journal of Strategic Management*, *4*(4), 1–9. https://doi.org/10.70619/vol4iss4pp1-9

van Leeuwen, J. P., Hermans, K., Jylhä, A., Quanjer, A. J., & Nijman, H. (2018). Effectiveness of virtual reality in participatory urban planning: A case study. In *Proceedings of the 4th media architecture biennale conference* (pp. 128–136). Association for Computing Machinery. https://doi.org/10.1145/3284389.3284491

Wilson, A., & Tewdwr-Jones, M. (2022). *Digital participatory planning: Citizen engagement, democracy, and design*. Routledge. https://doi.org/10.4324/9781003190639

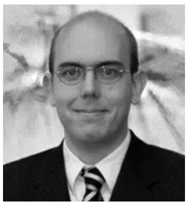
Wolf, M., Söbke, H., & Wehking, F. (2020). Mixed reality media-enabled public participation in urban planning. In T. Jung, M. C. tom Dieck, & P. A. Rauschnabel (Eds.), *Augmented reality and virtual reality: Changing realities in a dynamic world* (pp. 125–138). Springer. https://doi.org/10.1007/978-3-030-37869-1_11

Zimmermann, J., Konrad, S., & Nerdinger, F. W. (2009). *Bedarfs- und Anforderungsanalyse zur Entwicklung einer internetbasierten Kommunikationsplattform zur Unterstützung des Forschungstransfers* (Rostocker Beiträge zur Wirtschafts- und Organisationspsychologie No. 1). Universität Rostock, Lehrstuhl für Wirtschafts- und Organisationspsychologie. https://doi.org/10.18453/ROSDOK_ID00002241

About the Authors

Marc Schwarzkopf (M.Sc.) is a research associate and cluster manager for Innovation Management at Chemnitz University of Technology. His research focuses on sustainable mobility, cycling safety, urban infrastructure evaluation, citizen participation, virtual reality, and ergonomic methods for analysing socio-technical systems.

Miriam Reichert (M.Sc.) studied cognitive psychology at Chemnitz University of Technology. Her master's thesis examined virtual reality and citizen participation. She currently works as a usability expert in Budapest.



Holger Hoffmann (PhD) is a research associate at Chemnitz University of Technology, working at the intersection of innovation, human factors, and digital systems. He previously held research and leadership positions at Fraunhofer IAO, innosabi GmbH, and the University of Kassel.

Angelika C. Bullinger-Hoffmann is a professor of ergonomics and innovation at Chemnitz University of Technology. Her research addresses interactive innovation and the future of work. She has extensive experience in acquiring and leading national and European projects and advises organizations on innovation-related challenges.