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Quality Standards for XR Participation – Applications and Challenges in Smart, Participatory Urban Development

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1 ABSTRACT

The expanded communication, design and participation opportunities offered by XR technologies open up additional potential for participatory urban development. The spatial representation of planning variants can promote understanding of the planning object and informed opinion-forming among those involved (Brettschneider et al. 2017: 14; Wolf et al. 2020: 125f.; Rogoll, Sinning, Wolter 2024: 58). XR participation can be applied to various types of projects, such as redesigns of public spaces or urban development framework plans, as well as to various fields of urban development, such as open space planning, mobility and building construction planning.

The article addresses the following questions: What significance can XR technologies have for sustainable participatory urban development in the smart city? Which areas of application are particularly suitable? What are the potential benefits and challenges of using XR-supported participation formats? What quality standards can be identified for XR participation formats to supplement established participation guidelines for participatory urban development processes?

Quality standards for democratic participation have not yet been defined for the implementation of XR participation (using AR technology or in virtual space or the metaverse). Although citizen participation guidelines have now been established in many municipalities, there is a lack of supplementary guidelines for the use of digital participation with the support of XR technologies. In the context of the interdisciplinary and transdisciplinary BMFTR joint research project "XR-Part: XR participation spaces for expanded social participation in urban transformation processes" using the example of participatory planning processes in the model cities of Mannheim and Rostock, quality standards for XR participation were identified on the basis of empirical surveys during the testing of XR participation formats. They can contribute to the effective and sustainable design of XR-supported participation procedures in planning processes and ensure broad and committed participation. These quality standards range from targeted process design and time management, access equity, target group-oriented participation format design, legitimisation of visualisations, relevant visualisation of planning content, ethical, social and legal implications, to evaluation and continuous improvement of XR-supported participation formats.

Keywords: XR-Technology, Participatory urban development, Quality standards, Smart city, participation format

2 PARTICIPATION WITH XR TECHNOLOGIES – AR, VR AND METAVERSE

XR stands for Extended Reality and is an umbrella term for all immersive technologies that aim to expand human perception of reality. This includes digitally enhanced reality, such as VR (Virtual Reality), AR (Augmented Reality) or MR (Mixed Reality) (Dörner et al. 2019, among others). AR – Augmented Reality means “extended reality”. In augmented reality, virtual objects such as 3D models, images or text elements are digitally inserted into real space so that they are visible to viewers through mobile devices such as smartphones, tablets or AR glasses. Augmented reality also enables the placement of and interaction with digital content in the immediate physical environment (Wölfel 2023: 16, Dörner et al. 2019: 1ff.). The term VR – virtual reality refers to a completely computer-generated, three-dimensional environment. In VR, users have the feeling of being immersed in another world with which they can interact. Their perception of the real world is completely blocked out. The virtual environment is projected in front of the user’s field of vision using special multisensory devices such as head-mounted displays (HMDs) (Mystakidis 2022: 187). The “metaverse” is described as an immersive and interactive virtual space that can be considered the next

generation of the internet. Currently, there are metaverse applications from various providers, such as Decentraland, Second Life, Mozilla Hubs, TriCAT spaces and the Horizon Worlds platform from Meta. VR and AR technologies allow users to enter this virtual world and interact with it. Users of these virtual worlds interact with each other as avatars. (Weinberger 2022: 1; Fegert 2023: 2; Mertes et al. 2023: 8). The desktop application is currently easily accessible to users, while the application with VR glasses requires availability, which means a higher inhibition threshold. XR participation can enhance communication as well as spatial perception and imagination of planning variants, thus facilitating citizens and stakeholders to develop a founded opinion on the planning options (Brettschneider et al. 2017: 14; Wolf et al. 2020: 125f.; Rogoll, Sinning, Wolter 2024: 58).

3 POTENTIAL AND APPLICATION OF XR PARTICIPATION

3.1 Potential of XR-Participation

Next to its potential for expanded communication in planning projects, XR-supported participation offers a variety of benefits for participatory urban development processes. Inclusive and low-threshold participation can be promoted by the fact that XR formats increase motivation to participate and support the imagination of participants (Fegert et al. 2020: 2f.). Thanks to their immersive and interactive design, XR participation formats appeal to new target groups that have previously been largely overlooked by traditional formats, and their use is not restricted by time or location, thus enabling greater opportunities for participation.

Younger or tech-savvy individuals in particular are more easily won over to participation processes, which can increase the reach and diversity of participants (Rogoll, Sinning, Wolter 2024). In addition, the playful nature of many XR formats can increase overall motivation to participate (Simonofski et al. 2024: 10) and thus counteract the participation paradox, according to which there is little public interest in early planning phases despite a high degree of decision-making freedom (Berlin Senate Department for Urban Development and the Environment 2012: 82; Hirscher 2017: 323f.).

Immersive visualisations make it easier for citizens with varying levels of prior knowledge to access complex planning topics and to develop an informed opinion (Fegert et al. 2020: 1). 3D visualisations can counteract subjective interpretations, make it possible to experience things that are difficult to imagine, and increase transparency between the city and its citizens. In addition, XR participation formats enable flexible participation for different population groups, such as families, working people, or people with limited mobility. In addition to analogue formats, AR, VR and virtual collaboration spaces can open up alternative avenues for democratic participation and promote comprehensibility, collaboration and interaction in planning processes (Wolf et al. 2020: 125f.).

3.2 Areas of application for XR participation

Potential use cases for XR participation are manifold, ranging from the redesign of urban squares, green space planning, mobility and building construction planning to urban development framework plans. XR participation formats are particularly suitable in process phases in which 3D visualisations of development variants are possible or planned. These include mission statement processes, the establishment of framework plans, integrated development concepts (ISEK), scenario and alternative planning, and action planning.

In practice and research, XR technologies are already being used in numerous areas of urban planning. In transport planning, for example, AR and VR applications enable the simulation of alternative road layouts, the redesign of street spaces, or the visualisation of sustainable mobility concepts. This allows citizens to develop informed assessments of design options, as in the “VR-Planning” project in Vienna (Schrom-Freitag et al. 2018). XR technologies are also being used in the development of public spaces and the design of residential environments, for example in the “CoHeSIVE” project in Eindhoven, which investigated the potential of VR for healthy public spaces (Evers et al. 2023).

In addition, immersive visualisations can be used to clearly illustrate aspects of climate protection and climate adaptation, such as the shadows cast by buildings or temperature changes resulting from greening measures (GLARA-Forschungskonsortium 2021; Stadt Essen 2024). They also facilitate the evaluation of different structural development options in terms of their spatial impact (Brettschneider et al. 2017: 14). While AR is particularly suitable for blending new elements into existing urban space, VR also allows

objects to be hidden or removed and enables the vivid simulation of effects such as shadow casting, parking space development or lighting concepts (Brysch 2023: 461ff.).

XR technologies are also used in city marketing to bring urban space to life for shoppers or tourists, for example through AR-supported city tours such as "Thuringia.MyCulture" in Erfurt or "MauAR" to visualise the course of the Berlin Wall (Topouzova 2021: 98f.).

XR technologies can be used in both formal, legally regulated participation procedures and informal processes. They are particularly suitable for procedures involving the creation of concrete 3D visualisations, such as in urban planning competitions. In terms of participation intensity, XR formats can be used for information, consultation and active participation, right through to cooperative procedures. They are particularly suitable in the early stages of the process for initiating discussions about development models or scenarios and identifying the needs of those affected. This allows citizens' requirements to be taken into account at an early stage, for example when competitions are announced. With an appropriate cost-benefit ratio, XR participation opportunities can be used effectively for both large-scale projects spanning several years and small-scale projects.

4 RESEARCH CONTEXT: XR PARTICIPATION SPACES FOR EXPANDED SOCIAL PARTICIPATION IN URBAN TRANSFORMATION PROCESSES

4.1 Context Joint research project XR-Part

This article is part of the interdisciplinary and transdisciplinary BMFTR joint research project "XR-Part: XR participation spaces for enhanced social participation in urban transformation processes" using the example of participatory planning processes in the model cities of Mannheim and Rostock (Sinning et al. 2023). The objective of this project was to develop and evaluate participation formats based on XR technologies that comply with the quality standards of good citizen participation and can be integrated into cross-media participatory urban development projects. In line with this objective, the aim was to develop and design XR participation formats that enable flexible participation in terms of time and location, thus opening up new approaches to democratic planning processes. Based on trials in real participation processes in the model cities of Mannheim and Rostock, the extent to which the developed participation formats can improve the quality of participation procedures, both with AR technology (XR-Part participation tour) and in the metaverse (XR-Part participation space), was investigated. These formats can be used to overcome spatial and temporal constraints and enable citizens to participate in urban transformation processes through a comprehensive communication strategy that integrates both cross-media and analogue participation formats (Allianz Vielfältige Demokratie, Bertelsmann Stiftung 2017: 4 ff.; Le Blanc 2020: 4).

Digression: Cross-media participation offers a wide range of potential for more inclusive and broader participation processes: on the one hand, it offers a larger number of citizens the opportunity to participate (Le Blanc 2020: 9), On the other hand, cross-media participation can take into account target group-specific communication channels, individual preferences, and citizens' opportunities and barriers to participation, such as varying degrees of digitalisation, family and life situations, and accessibility requirements (Allianz Vielfältige Demokratie, Bertelsmann-Stiftung 2017: 15, 19, 22). By combining analogue or traditional on-site participation events with digital or online participation and information offerings, which complement each other, the different requirements for target group orientation and accessibility can be taken into account (Le Blanc 2020: 12).

4.2 XR participation formats

The XR participation system developed in the XR-Part research project consists of an AR component, the XR-Part participation tour, and a metaverse application, the XR-Part participation room. These are presented below and explained in terms of their design and functionality.

XR-Part participation tour (see fig. 1): This is an AR application that allows users to display virtual models in the real environment on a tablet or smartphone in the relevant planning area. As part of the participation tour, three-dimensional visualisations of usage and design options are presented at designated stations, accessible via real world checkpoints, which can be viewed and commented on using the AR application. It is also possible to display information on the various development options in the form of text, images or video content. Additionally, a key feature of the app is the integrated survey tool. It allows participation

questions to be posed to participants or opinions and usage requirements to be gathered via multiple-choice and single-choice questions.

The integrated 3D object catalogue also offers participants the opportunity to independently place virtual street furniture and greenery elements in the space. In this way, design proposals can be submitted and appropriation needs can be located in a specific area with georeferencing.

Fig. 1: XR participation tour (Source: TriCAT GmbH, ISP der FH Erfurt 2024)

XR-Part participation space (see fig. 2): This is a three-dimensional, virtually immersive communication and meeting space (metaverse). Citizens, representatives of the city administration, moderators and, if necessary, other stakeholders come together in the virtual space as avatars (virtual images) and can work interactively and collaboratively on the topics and issues of the planning project. The virtual space can be accessed online via desktop or browser application on a PC or laptop. The virtual immersive XR participation space offers the opportunity to hold various moderated participation events, such as workshops or dialogue formats, so that citizens can participate flexibly from home. Furthermore, it is possible to open the XR participation space persistently if required, for example to make 3D visualisations accessible to citizens without time restrictions in an interactive exhibition format. The XR participation space has various spatialities. The foyer is the starting point for all participants, as this is where the avatars enter the virtual space. The individual meeting rooms are available for (small) group work, while the auditorium with its seating tiers is a suitable space for presentations and lectures in plenary sessions. The adjoining spacious workroom is particularly suitable for presenting the 3D models of the planning area at different scales and bringing them to life. The three-dimensional replicas of the relevant planning areas can be viewed and explored from different perspectives, both as table models and as walk-in models on a scale of 1:1.

Fig. 2: XR participation space (Source: TriCAT GmbH, ISP der FH Erfurt 2024)

A 3D object catalogue (indoor and outdoor furniture, plants, play and sports equipment, etc.) and various interactive media walls enable a wide range of participation methods to be implemented in the XR participation room in a novel, playful form. These include, for example, map and point queries, mapping or modular methods, and participation methods such as World Café or Fishbowl. Detailed explanations can be found in the evaluation report (Rogoll, Sinning, Wolter 2024: 8f.).

The XR participationformats, XR-Part partcipationspace and XR-Part AR application weredeveloped conjointly, combining immersive visualisations of planning variants with the opportunity of collaborative

exchange, surveys and commentfunctios. The latter make it possible to obtain qualitative feedback and quantitative opinions. The individual formats of the XR system shouldbe used independently of each other or linked to-gether. Together with analogue and other digital participation formats, they form a broad and flexible range of participation options.

Both AR-supported participation and participation opportunities in virtual space (metaverse) offer various possibilities for implementing innovative and classic participation methods thanks to their integrated tools and functions. One advantage of XR participation applications over analogue formats is that they allow methods to be carried out with less preparation and thus more efficiently.

In addition to the technical XR applications developed, the project's key findings, which are discussed in this article, include recommendations for action and quality standards for the implementation and integration of XR participation, which were identified on the basis of empirical surveys conducted during the testing of XR participation formats (Sinning, Brandenburger, Kruse, Rogoll 2023; Rogoll, Sinning, Wolter 2024; Rogoll, Sinning, Wolter 2025a; Sinning, Rogoll, Wolter, Henn 2025).

5 QUALITY STANDARDS FOR IMPLEMENTING XR PARTICIPATION FORMATS

Conventional guidelines for effective and inclusive citizen participation in urban planning processes have already been widely established in municipal practice. However, the quality standards for citizen participation have not yet been adapted for XR-based participation, which his what the XR-Part research project aimed to accomplish. These quality standards range from targeted process design and time management, access equity, target group-oriented participation format design, legitimisation of visualisations, relevant visualisation of planning content, ethical, social and legal implications, to the evaluation and continuous improvement of XR-supported participation formats. All affected citizens should have a fair chance to participate and voice their opinion (cp. Nederhand, Edelenbos 2022: 526). In times of social transformation, it is the responsibility of local authorities to ensure the interests of democratisation by involving citizens in these processes (e.g. mobility transition, climate adaptation) and by taking into account their concerns over complex development procedures. Combining different formats geared towards diverse participation requirements ensures that a broad target group is addressed and opens up various (low-threshold) access points (Nederhand, Edelenbos 2022: 526). It is important that the different formats are equivalent in terms of their degree and quality of participation, so that citizens' opportunities to participate do not depend on the medium chosen or available to them (Fischer et al. 2020: 134; Steenbergen et al. 2003: 25).

The following section outlines the quality standards that have been identified for XR participation formats from the specialist literature and the findings of trials and evaluations conducted as part of the XR-Part joint research project (see Fig, 3), which supplement the established participation guidelines for participatory urban development processes (for more details, see Rogoll, Sinning, Wolter 2025b).

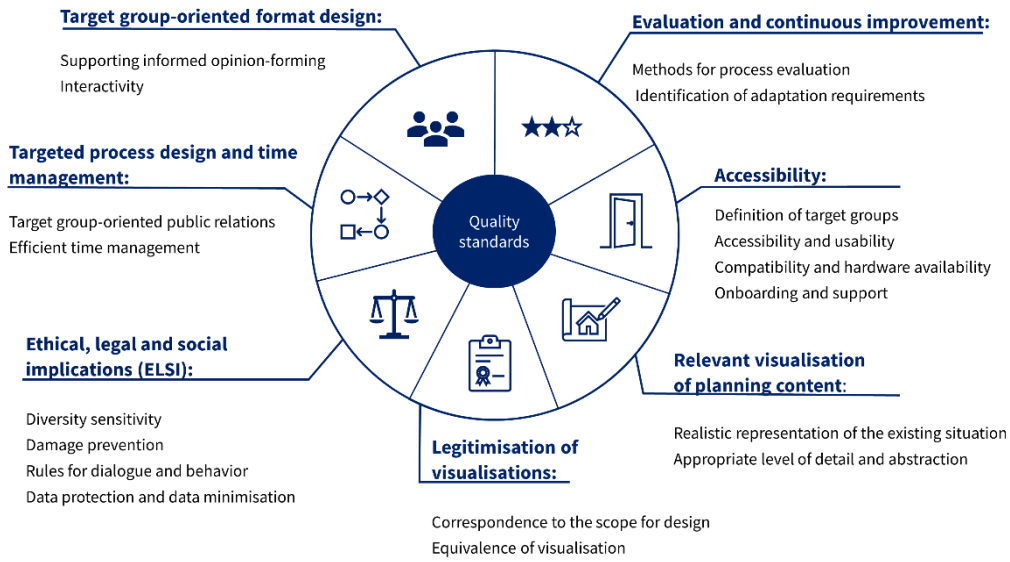

Fig. 3: Quality standards for XR participation (Source: ISP der FH Erfurt 2026)

5.1 Targeted process design and time management

The integration of XR-supported participation opportunities into a cross-media process requires an adapted procedural concept that takes additional work steps into account in the schedule. In addition, the success of XR-supported procedures depends on appropriate advertising and addressing the target citizens.

Target group-oriented public relations: In order to adequately introduce people with varying levels of prior knowledge in the field of technology to XR technologies, it is necessary for preparatory public relations work to promote XR participation formats in an easily comprehensible manner. Depending on the target groups addressed, promotion and information should be provided through various channels, such as press releases, social media posts, posters, postcards, etc. (Goldschmidt 2014: 325f.; Nanz, Fritsche 2012: 28; Stiftung Mitarbeit 2021). The use of visual media makes it possible to arouse curiosity about the XR-supported participation formats and allows participants to familiarise themselves with the planned XR formats in advance. “Teaser images” in press releases or social media posts provide an insight into how XR technologies are used in participation. Video tutorials teach citizens how to use XR applications, making it easier for them to access XR technologies and dispelling any reservations they may have in advance.

Efficient time management: Management should allow sufficient time to incorporate feedback and contributions from the XR participation events into the planning project (DIN EN ISO 9241-210: 41). The time frames for planning, implementing and evaluating the participation formats need to be estimated realistically so that a concrete schedule for the realisation of the development project can be drawn up (Goldschmidt 2014: 273).

5.2 Accessibility

Accessibility in citizen participation is essential in order to give all members of society, regardless of their individual circumstances, a fair opportunity to participate in the process of shaping society. This is not only a matter of providing diverse opportunities for participation, but also of breaking down existing barriers, whether physical, linguistic, cultural or digital.

Definition of target groups: When defining target groups in the context of planning the participation process, it is necessary to describe both the groups of people who are to be specifically reached with the XR participation formats and those who are excluded from using XR technologies or whose access to these technologies is significantly restricted (Huning 2014: 39f.; Orthmann 2017: 12f.). In the interests of equal access, it is necessary to offer alternative participation options to people with limited access to XR technologies, such as people with motor impairments (DIN EN ISO 9241-210: 22; ISO 9241-112: 2017, 3.15; BITV 2.0).

Accessibility and usability: Ensuring that XR participation formats are accessible to as large a user group as possible is a key objective. This can be achieved by implementing a barrier-free design, such as the integration of subtitles or the provision of alternative input methods (Dirks, Bühler 2018: 8f.).

The user interface of the XR application used should be intuitive, easy to understand and clearly laid out to enable easy navigation. It must be ensured that users can quickly learn how to use XR technologies. The text-to-speech function allows information about the process, participation questions, etc. to be read aloud in the applications. A speech-to-text function should be included to facilitate the entry of comments. This is particularly relevant for user groups who are less practised or limited in their ability to type manually on the device keyboard. Furthermore, the language choices available must be suited to migrant populations affected by the subject of participation to ensure equal participation opportunities (Goldschmidt 2014: 194). Appropriate graphic, performance and technical quality is guaranteed, ensuring an immersive and realistic experience (Molich, Nielsen 1990).

A successful augmented reality (AR) application depends on several technical and environmental criteria. Firstly, the recognition and tracking of real objects in the environment is crucial. This requires precise registration and calibration so that digital content can be embedded stably and accurately in the physical world (Azuma 1997: 360; Billinghurst et al. 2015: 89; Sutherland 1968: 759). The user experience and interactivity also play a central role, especially in terms of the visual and cognitive load on users. Aspects such as latency, overlay accuracy and application response speed are crucial to the success of an AR application (Azuma 1997: 361; Milgram, Kishino 1994: 133; Zhou et al. 2008: 2).

Compatibility and hardware availability: Ensuring that XR participation formats function on different devices and platforms is an essential criterion for achieving a broad user base. XR applications should be compatible with various common software solutions (Android, iOS, Windows, macOS) and hardware components (tablets, smartphones, PCs). It must be ensured that the content is displayed responsively (optimised for different end devices) so that the target group can participate using their private end devices (PC, laptop, mobile phone, tablet) (Koch et al. 2014: 142).

In order to enable target groups with limited access to digital transformation to participate, end devices (laptops, tablets, smartphones) should be provided free of charge or available for loan by the initiators. This can be seen as a response to the first level digital divide.

In particular, VR and AR glasses are not currently part of standard household technical equipment and should therefore be provided free of charge for participation (Bitkom e.V. 2022). Additionally, free Wi-Fi is an important prerequisite for access, especially for on-site applications.

Equipment for AR applications often includes head-mounted displays (HMDs), mobile devices such as smartphones or tablets, and special cameras and sensors. These technologies must ensure high precision and stability when superimposing digital content, while also being robust enough to be used in difficult weather conditions (Azuma 1997: 370; Billinghurst et al. 2015: 105; Sutherland 1968: 762). They must also be light and comfortable enough for long-term use so as not to impair the user experience (Billinghurst et al. 2015: 108; Henderson, Feiner 2011: 543).

Onboarding and support: When using XR participation formats, it is important to provide a clear explanation of how these applications work and how they can be used in the overall process from the outset (see, among others, Initiative D21 e.V. 2020). This leads to comprehensive education and enables a larger group of people to access the benefits of these innovative technologies.

It is advisable to provide participants with appropriate and adaptive onboarding methods and interactive tutorials tailored to their different degrees of knowledge and technical skills in order to ensure successful integration (Koch et al. 2014: 151). Examples include explanations with visual and acoustic presentations or interactive tutorials that promote “learning by doing”. People with little prior knowledge should be able to take advantage of comprehensive support services. Support can be provided, for example, by means of a help button, an FAQ page, technical support or a virtual guide. People who are very tech-savvy, on the other hand, should be empowered to use XR technologies more independently by receiving only the most necessary information and being able to skip tutorials.

5.3 Target group-oriented format design

Designing participation formats tailored to specific target groups is essential for ensuring inclusive and effective citizen participation. This requires coordinating participation opportunities and communication channels in order to address the specific needs of different target groups within the population. XR participation formats offer the opportunity for interactive participation on the one hand and, on the other hand, can encourage the formation of opinions on the subject of participation.

Supporting informed opinion-forming: When designing an XR participation format, it is particularly important to take into account the level of knowledge and information of the participants, which can vary greatly depending on the respective circumstances (Goldschmidt 2014: 108). The provision of content that is characterised by high quality, relevance and careful research is crucial in order to enable those involved to evaluate and prioritize visualisations of planning projects or variants in a differentiated manner. The use of XR technologies can help to promote knowledge acquisition and imagination through 3D visualisations, thereby limiting the scope for interpretation by those involved (Goudarznia et al. 2017). In order to prevent individual misinterpretation of presented content or concepts, transparent, appropriate communication is essential to bring all stakeholders to the same level of knowledge (Rockmann et al. 2015).

Interactivity: Active user participation is encouraged through the integration of interactive features, including polls, surveys, discussion forums, virtual tours and simulations. The methodological design of the participation formats can take on a playful character, which can increase the users’ motivation (“joy of use”) (Masser, Mory 2017: 57; Rohde et al. 2010: 345f.; Hoffmann 2023: 10ff.). A station concept in the real-world planning area or its virtual model, for example, proves to be suitable for carrying out small group work in the style of a World Café or for subdividing the event thematically.

Social interaction is a fundamental need for participants (Bennett et al. 2021: 30). When designing XR participation formats, it is therefore important to ensure that exchange between the various stakeholder groups (and within the stakeholder groups) is facilitated. Guided tours with an AR app are one example of how this approach can be implemented. Another option is a moderated dialogue format, such as idea workshops, which can be held in the virtual space.

In addition to choosing suitable participation formats and methods, it is important to select a virtual space with appropriate features (large conference room, small work rooms, outdoor area, naturalistic colour scheme, neutral ambience, audio rooms, etc.) that is appropriate for the target group when organising events in the metaverse.

5.4 Legitimisation of visualisations

A fundamental prerequisite is that, in addition to the participation process itself, visualisations presented to citizens and other stakeholders must also be politically and administratively legitimate. Authorisation or legitimisation depends on the following parameters:

Correspondence to the scope for design: The visualisations created within the XR application, which include 2D or 3D models and object catalogues, reflect the basic scope for design and show only those scenarios that are theoretically feasible from the perspective of the specialist departments and planners involved. In order to check the feasibility of development variants, a feasibility study can be carried out in advance, for example.

Equivalence of visualisation: Manipulation of the viewer is avoided by presenting different development options in an equivalent and representative or typical manner. The selected 3D visualisations should therefore have a uniform style (shape and colour scheme, texturing, level of detail) and be equally abstract.

5.5 Relevant visualisation of planning content

To ensure that the 3D visualisations shown in the XR participation formats are relevant, two conditions must be observed. On the one hand, the current state must be depicted realistically, and on the other hand, an appropriate degree of abstraction and level of detail must be selected.

Realistic representation of the existing situation: The creation of models of the built environment and the use of 3D city models requires a factually correct representation. The 3D city model should depict the current actual state of the participation object in a manner that is appropriate to reality and recognisable, as well as correct dimensions, proportions, shapes and colours (Brettschneider et al. 2017: 39). The 3D model should depict the defined participation object in its entirety and include relevant context of the surrounding area. In certain cases, an exemplary sub-area may also be visualised, provided that there is a corresponding justification for this. For example, a map should be used to show participants how the model is spatially limited and to which area the participation project relates (ibid.: 30f.).

Appropriate level of detail and abstraction: When creating 3D representations of planning projects and the object catalogue, they must have an appropriate level of abstraction, conveying complex, crucial and understandable information about the object, highlighting the general conditions and limitations of the planning project or the objects depicted, yet not making concrete design proposals (Höhl, Broschart 2015: 23). Therefore, when creating 3D models, it is important to refrain from integrating irrelevant details that could impair or distract from the discussion of content (Brettschneider et al. 2017: 39).

The degree of abstraction and the level of detail of 3D development variants and objects should be selected depending on the progress of the participatory planning process and the associated objectives. In the early phases of planning and participation, for example, rough cubatures of building volumes and interpretable 3D pictograms can be used to visualise development themes and requirements. In advanced planning phases, on the other hand, a high level of detail in the presentation of development variants is recommended in order to enable participants to make a comprehensive assessment.

5.6 Ethical, legal and social implications [ELSI]

The overarching goal is to use technology responsibly, with a focus on successful human-technology interaction. It must be ensured that the use of XR technologies is ethically acceptable and does not have any adverse consequences for users (Gressel et al. 2019: 11).

Diversity sensitivity: In order to make XR applications more inclusive and reflect the diversity of society, it is advisable to pay attention to diversity-sensitive issues when choosing a software provider and designing XR participation formats:

People with physical or mental impairments should have equal opportunities to participate. In addition to the accessible design of the XR application, the participation concept can define what support services are available for these target groups, e.g. through needs-based support or special workshop formats.

The visual representation as an avatar and the associated effect has a significant influence on the interaction between the actors (citizens, administration, politicians, moderators). Avatars should therefore be individually customisable in order to reflect characteristics such as gender identity, skin colour, different body shapes or physical impairments. It is also advisable to avoid stereotypical and discriminatory representations in public relations work. Images of conversation situations should depict people at eye level (Goethe University Frankfurt am Main, Equal Opportunities Office 2016: 22ff.).

Diversity-sensitive communication, in particular through multilingualism, plain language or gender-neutral language, can ensure that all target groups are addressed in the participation processes and can adequately contribute their wishes and ideas.

All these aspects can be summarised under the heading of diversity-sensitive technology design. Key questions for assessing diversity-sensitive technology design and thus the equal participation of target groups in XR-supported participation processes are: "For whom is the technology being designed? [...] Who actually benefits from the technology and who might be harmed, marginalised or even “erased” from an epistemic perspective due to its design or implementation? What features are missing to meet the needs and preferences of diverse users [...]?" (Heesen et al. 2021: 137f.).

Damage prevention: The use of mixed reality technologies must not result in undesirable effects or health risks for those involved (ibid: 11). This also implies the prevention of psychological, physical and economic damage. Furthermore, the prevention of motion sickness, anxiety and panic situations is of essential importance. Ensuring the safety of participants is a primary requirement when using immersive technologies (DIN EN ISO 9241-210: 38).

When using VR headsets in particular, the heightened immersive experience means that users need to be accompanied and supervised in order to reduce fears and uncertainties and to provide support in the event of negative sensations such as motion sickness, fear of heights or anxiety. When using AR technology, it is also necessary to alert users to potential hazardous situations (both during onboarding and during use). Dangerous situations can arise, for example, when walking with the device, due to a focus on the display and a resulting impairment of perception of the real environment, with a risk of tripping or falling, overlooking vehicles or other objects.

Rules for dialogue and behaviour: Compliance with established rules for dialogue and behaviour is ensured by preventing manipulation and inappropriate contributions by participants (e.g. sexist, racist contributions or misinformation). This can be achieved through (trained, sensitised) moderation or technical measures, such as filtering contributions (Goldschmidt 2014: 163).

Data protection and data minimisation: It must be ensured that XR applications meet data protection compliance requirements (creation of and adherence to a data protection concept). Transparent communication about data use and obtaining user consent are essential in this regard. In the interests of privacy, personal data is to be collected purposefully and economically in the participation process (German Ethics Council 2017: 132; Kuhnert, Grimm 2020: 255), carefully weighing options such as pseudonymised participation against possible negative consequences like manipulation or distortion of the participation results.

When installing AR applications on private devices, users must be informed about the possibility of location data tracking in accordance with data protection regulations. In order to enforce data protection and maintain an open, deliberative discussion atmosphere, it is also necessary to detect recordings and screenshots and protect the XR application from them. Alternatively, loan devices with pre-installed applications can be provided as part of accompanied participation tours.

5.7 Evaluation and continuous improvement

Continuous optimisation of XR participation formats is achieved through regular reviews and adjustments. Therefore, mechanisms such as evaluation forms need to be implemented. Both user feedback and technological developments should be taken into account.

When evaluating XR participation formats, it is necessary to identify technical adaptation requirements in addition to procedural aspects for embedding them in the overall process. This includes the design of user interfaces, compatibility with hardware and software, and the precision of content localisation. These requirements must be communicated to the technology provider (developer). Aspects of the evaluation of XR participation formats can be integrated into already established evaluation procedures for analogue or cross-media participation processes by the municipality. By defining evaluation criteria and derived questions, the success and effectiveness of the participation format can be assessed.

6 CONCLUSION: QUALITIES FOR XR PARTICIPATION FORMATS IN CROSS-MEDIA STRATEGIES

As shown, XR technologies expand the possibilities for communication, design and participation and open up additional potential for participatory urban development in the smart city. The spatial representation of planning variants promotes understanding of the planning object and enables participants to form well-founded opinions (Brettschneider et al. 2017: 14; Wolf et al. 2020: 125f.; Rogoll, Sinning, Wolter 2024: 58). XR participation is suitable for different types of projects – such as redesigns of public spaces or urban development framework plans – as well as for various fields of action such as open space planning, mobility and building construction planning. While AR technologies are particularly suitable for visually supplementing real spaces (e.g. building extensions or design elements), participation formats in the metaverse enable more comprehensive and fundamental interventions in the project area, for example in terms of space distribution or morphology.

With regard to the expanded opportunities for participation, there was a generally positive response to XR participation formats across different age groups and among participants with varying levels of technical knowledge. Even those who were initially inexperienced were able to achieve significant learning success in a short period of time.

Through functional enhancements such as text-to-speech, speech-to-text and multilingualism, XR technologies can also break down barriers and facilitate the participation of people with visual or hearing impairments and those who speak foreign languages (Rogoll, Sinning, Wolter 2024: 64).

A key challenge is that XR participation formats for administrations are currently still time-consuming and costly. This makes it all the more important to ensure that the results can be applied in municipal practice, for example by reusing the 3D models in later planning phases and everyday work processes. Examples of this include implementation planning with Building Information Modelling (BIM), which enables precise visualisation of complex plans and can reduce planning errors (Wong et al. 2018: 108, 114), as well as working with urban digital twins. The latter can be used by different departments for monitoring, management and planning. The Connected Urban Twins research cluster of the cities of Hamburg, Leipzig and Munich demonstrates a wide range of possible applications – from monitoring traffic flows, social displacement effects and air quality via a municipal energy atlas to civil engineering and transport planning from a first-person perspective (Keler et al. 2023; Winter 2023; Schubbe et al. 2023: 16, 19; Lindner et al. 2022).

In order to exploit the potential of urban digital twins as a real-time data environment, planning tool and participatory space, local authorities must create appropriate organisational structures and integrate digital and XR-supported methods into their everyday workflows. This requires time, financial and human resources, as well as the relevant expertise for data preparation, maintenance and integration. In addition to technological openness, fault tolerance is also necessary in order to create space for technological developments.

Support for local authorities from the federal and state governments is essential in order to pool and disseminate knowledge and promote networking opportunities. In order to involve citizens in digital municipal (participation) processes, media education in schools and adult education should be promoted,

especially for socially disadvantaged population groups, which are often underrepresented in participation processes.

Despite their high potential, XR participation formats should always be used as a supplement to analogue and other participation formats so that no one is excluded from democratic participation. This requires cross-media communication strategies and participation concepts in which the interfaces between analogue and digital formats are considered from the outset.

The quality standards developed contribute to the qualified use of XR technologies in communicative planning processes. They complement existing municipal participation guidelines and regulations and can support municipalities, administrations, service providers and other users in consolidating and professionalising the use of XR technologies.

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