

Application of ICT in spatial planning



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Dissertation thesis

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Statement

I hereby declare that I have independently elaborated the dissertation thesis “Application of ICT in spatial planning” and that I have cited all the information sources that I used in the thesis, which are listed at the end of the thesis in the chapter [References](#).

Some of the work presented in chapters [3](#) and [4](#) was previously published as an article in the scientific journal “PRESENCE: Virtual and Augmented Reality” by the Massachusetts Institute of Technology. The specific parts of this dissertation that further develop the aforementioned article are referenced as follows: (Kabrhel & Mañas, [2025](#)).

In Prague on October 26, 2025.

Ing. Jan Kabrhel

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Whether through intellectual exchange, or “simply” encouragement and assistance, your help has made this research possible and more enjoyable. This work would not have been the same without your goodwill and support.

Abstract

This dissertation explores the use of information and communication technologies (ICT) in spatial planning, with a particular focus on tools of extended reality (XR) and its potential in facilitating public participation in the planning process. The central theme is the relationship between the degree of participation, the openness of decision-making processes, and the legitimacy of planning outcomes. The thesis identifies and describes various levels of immersion associated with visualisation methods used in planning, positing that higher levels of immersion are linked to a deeper understanding of the presented content by participants. At the same time, the study highlights potential risks of distortion and manipulation that may increase with the level of immersion.

Building on a synthesis of prior research, the study develops recommendations for the effective and responsible use of ICT technologies in planning processes. The analysis takes into account the specificities of institutional settings as well as different forms of public participation. The outcome is a set of proposals aimed at improving communicative capacity, transparency, and the quality of decision-making in spatial planning through digital tools, along with suggestions for future research directions.

Keywords: spatial planning, visualisation, participation, co-creation, 3D, augmented reality, augmented virtuality, virtual reality

Abstrakt

Disertační práce se zabývá využitím informačních a komunikačních technologií (ICT) v územním plánování, se zvláštním důrazem na nástroje rozšířené reality (XR) a jejich potenciál v participaci veřejnosti v plánovacím procesu. Ústředním tématem je vztah mezi mírou participace, otevřeností rozhodovacích procesů pro přijímání zpětné vazby od občanů a legitimitou výsledků plánování. Práce identifikuje a popisuje různé úrovně imerse visualisačních metod používaných v plánování, přičemž vyšší úroveň je spojována s hlubším porozuměním prezentovaného obsahu účastníkům participace. Práce však současně upozorňuje na možná rizika zkreslení a potenciální manipulace, která se může s rostoucí imersí zvyšovat.

Výzkum syntetizuje poznatky z již publikovaných studií, a i na jejich základě formuluje doporučení pro efektivní a odpovědné využití ICT technologií v plánovacím procesu. Zohledněna jsou přitom specifika institucionálního prostředí i různé formy participace. Výsledkem je soubor návrhů, který může zlepšit komunikační kapacity, transparentnost a kvalitu rozhodování v územním plánování s využitím digitálních prostředků stejně, jako další možnosti výzkumu.

Klíčová slova: územní plánování, visualisace, participace, spoluvytváření, 3D, rozšířená realita, rozšířená virtualita, virtuální realita

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C'est le réel, et non la carte, dont des vestiges subsistent çà et là, dans les déserts qui ne sont plus ceux de l'Empire, mais le nôtre. Le désert du réel lui-même.

Jean Baudrillard (1981), *Simulacres et Simulation*

It is the real, and not the map, whose vestiges persist here and there in the deserts that are no longer those of the Empire, but ours. The desert of the real itself.

Jean Baudrillard (1994), *Simulacra and Simulation*

1

Introduction

SPATIAL PLANNING is not merely a process of regulating land use; it is increasingly becoming a complex negotiation concerning the form, functions, and values of space. Central to this process is the question of how to accommodate diverse interests and how to create a platform for the expression of those directly affected by planning outcomes. In this context, public participation goes beyond formal commenting on proposals and becomes part of a broader effort towards inclusive and transparent planning that recognises residents as active co-creators of their environment. However, this participation only fulfils its purpose when the public is enabled to understand the proposed changes in their specificity, scale, and spatial implications.

Traditional means of communication (e.g. maps, plans, drawings or texts: described in detail in chapter 4.1) often fall short in enabling the general public to fully comprehend the spatial and contextual implications of proposed interventions: fully representing space in its spatiality, at a scale that corresponds to human experience, and within a context that is understandable without specialised training. Knowing only the zoning regulations or functional area boundaries is not enough. People need to see what a specific building will look like on the street they walk through every day, how a street corner will change, what impression a new neighbourhood will create, what the view from a window will become, or where a pedestrian route will lead. Particularly challenging can be the understanding of abstract concepts commonly used in spatial planning, such as floor area ratio (FAR), building coverage ratio (BCR), green area ratio (GAR) or open space ratio (OSR).

Although these values are crucial for the resulting form of the environment, they are difficult for most people to visualise. However, when these are translated into specific spatial representations and visualised directly within the locality or territory they pertain to (through virtual or augmented reality tools), they become more comprehensible. Participants in the process are then no longer dependent on abstract figures or textual rules, but can directly observe how a particular coefficient manifests in the height, volume, development intensity, or extent of green areas in a given location. This level of visual clarity significantly facilitates orientation within planned conditions and supports more informed and meaningful public engagement.

Emerging information technologies (particularly augmented and virtual reality: described in detail in chapter 4.2) offer tools to convey such spatial representations. They enable the creation of models not only of individual buildings but also of entire street profiles, squares, or neighbourhoods, integrating them into the existing environment. The accuracy and spatiality of these visualisations enhance the ability of the public to understand what is being proposed, how it will impact a specific place, and what dimensions and character the newly designed spaces will assume. Thanks to the availability of digital data, it is possible to generate content that is not only factually precise but also accessible to a wide range of users.

While some countries, such as Austria and Switzerland (Othengrafen et al., 2023) or Japan (OECD, 2023), are already actively utilising these possibilities and integrating them into participatory processes, elsewhere the

use of emerging information technologies remains marginal or entirely absent. The approach adopted by different countries, the themes explored in this context, and the level of technological and methodological advancement visible in various parts of the world represent an area that deserves systematic attention.

VIRTUALISATION, understood as the process of creating a digital simulation of reality, enables the representation of complex phenomena, relationships, and structures through virtual models (Oxford English Dictionary, 2024). In the context of spatial planning, virtualisation takes on a significantly new role: it becomes a mediator between the abstract language of regulations and the tangible spatial perceptions of stakeholders, bridging the gap between the professional realm of planners and the everyday experiences of the public. In other words, virtualisation is not merely a technological tool, but may function as a functional connection between professional and non-professional perspectives. The communication of planned interventions through innovative visualisation methods, such as augmented reality (AR) and virtual reality (VR), allows the public to form concrete mental images of future changes, thereby substantially enhancing their capacity to meaningfully engage in planning processes.

Experience from different sectors shows that main factor in the effectiveness of virtualisation is its ability to induce a sense of “immersion” that describes the effect where user’s awareness of being exposed to illusory stimuli fades into the background to such an extent that the virtual environment

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is perceived as real (Kersten et al., 2021). In other words, immersion is a psychological state where users momentarily forget they are engaging with a simulated environment and begin to perceive the virtual space as real. This psychological effect facilitates a deeper understanding of complex spatial structures and their meanings. In the field of urbanism and spatial planning¹, immersion holds significant practical value, as it enables the public to “enter” a design and comprehend its implications from the perspective of everyday experience (e.g. from the viewpoint of a pedestrian on a street, a resident in an apartment or a user of public park). This mode of perception, achieved through spatial simulation, goes far beyond the capacities of traditional maps, drawings, or verbal descriptions, which tend to abstract away from human scale and sensory perception.

With the continuous development and miniaturisation of information and communication technology (ICT), the use of AR and VR technologies has become a common standard across a wide range of disciplines, from agriculture (Becker et al., 2017), army (Wahyudi & Infantono, 2017), architecture, construction, and engineering (Z. Lin et al., 2022; Olsson et al., 2012; Riera et al., 2015; Sidani et al., 2021; Woodward & Hakkarainen, 2011), education (Martín-Gutiérrez et al., 2017), mechanics (Mourtzis, 2020), medicine (Furman & Hsu, 2021; McKnight et al., 2020; Müller et al., 2020;

¹ While “urbanism” often refers to the design and character of urban environments, “spatial planning” encompasses a broader, policy-oriented approach (including e.g. strategic planning and sectoral policies) to the organisation of land use across various spatial scales (European Commission, 1997). In the following text, only the term “spatial planning” will be used for consistency, in line with the established term *prostorové plánování* used in Czech planning discourse.

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Murali et al., 2021; Stromberga et al., 2021; Torous et al., 2021; Uddin et al., 2021), space exploration (Braly et al., 2019), sport (Richlan, 2025) and even in tourism, entertainment, and cultural heritage (Guttentag, 2010; Jang & Park, 2019; Tatic & Stankovic, 2024).

In spatial planning, these technologies are increasingly being adopted as well, which is suitable, because early public engagement is very important component in planning practice. Interactive visualisation enables the presentation of multiple solution options, comparison of their spatial implications, and even simulation of the impacts of proposed interventions on the daily lives of residents (Reaver, 2023; Wolf et al., 2020).

However, this powerful ability to simulate and communicate immersive future environments also entails significant risks. As noted by Boos et al. (2023) and Chen et al. (2022), there is a danger of cognitive overload², a state in which the amount of detail, stimuli, and visual input exceeds the limits of human perception. As a result, users may struggle to distinguish essential information from secondary elements, thereby weakening their ability to critically evaluate the spatial project designs they are meant to engage with. In such cases, the function of visualisation may transition to serving primarily as a tool for aesthetic enhancement and emotional influence, rather than facilitating informed public engagement and critical assessment.

² The term “cognitive overload” refers to a condition in which the cognitive processing capacity of the user is exceeded, impairing their ability to analyse or prioritise information. In the context of immersive technologies such as AR/VR, this state is often preceded or exacerbated by “sensory overload”, an excessive influx of sensory stimuli (e.g. visual, auditory) that overwhelms perceptual systems and contributes to subsequent difficulties in cognitive processing.

This problem becomes particularly acute in situations where visualisations are produced by parties with a direct interest in securing approval for a particular proposal, typically development firms or investors. In such cases, there is a risk of deliberate distortion of reality, for example by emphasising positive aspects (such as the presence of greenery, cleanliness of public spaces, or architectural quality) while downplaying negative impacts (such as realistically depicted traffic burden, overshadowing of surrounding buildings, or obstructing views). Elements like previous familiarity with the area (Jaalama et al., 2021), chosen viewing angle, lighting intensity, surface textures, and overall presentation style all play a significant role in shaping public perception of the project and, consequently, influence decision-making.

In this context, it is important to mention the classic concept of the “ladder of participation” introduced by Sherry R. Arnstein (1969), see figure 1 on page 9, which illustrates that participation is not always authentic or equitable. Its two lowest rungs “Manipulation” and “Therapy” explicitly describe situations in which information is presented selectively to steer participants towards a predetermined conclusion, without allowing them any real opportunity to influence anything. With the increasing use of digital visualisation tools, this manipulation increasingly occurs through visualisation: instead of transparently presenting a full range of options and all information, immersive visualisations can be used to generate persuasive representations of a preferred scenario, often fostering a sense of realism and credibility that traditional maps, plans, or textual descriptions cannot

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achieve. In the absence of a regulatory framework and independent oversight of the creation and interpretation of immersive visualisations, this utilisation of virtualisation in the participatory process increases the risk of becoming a tool for legitimising decisions that have already been substantively determined. This increased risk may entail more profound consequences than those identified by Arnstein (i.e. risk of manipulation using traditional visualisation methods such as maps, plans and texts), as digital visualisations can be systematically designed to optimise public perception and emotional engagement, potentially reinforcing predefined outcomes more effectively than traditional visualisation methods.

Generally, it is not inherently good to aim for the highest rungs of Arnstein's ladder of participation (Arnstein, 1969), as strengthening citizen control beyond borders could risk undermining representative democracy. Simultaneously, the ladder itself has been critiqued as overly simplistic and linear, failing to capture the complexity and diversity of participatory processes (Lauria & Schively Slotterback, 2021; White & Langenheim, 2021). Nevertheless, its clarity and illustrative power make it valuable for understanding varying degrees of participation, especially in context of preventing misrepresentation or manipulation.

At the same time, the use of advanced visualisation methods and the degree of public participation are not evenly distributed across the globe. As indicated by the democracy index (DI) (Economist Intelligence Unit, 2023), countries with a higher level of democratic culture and institutional

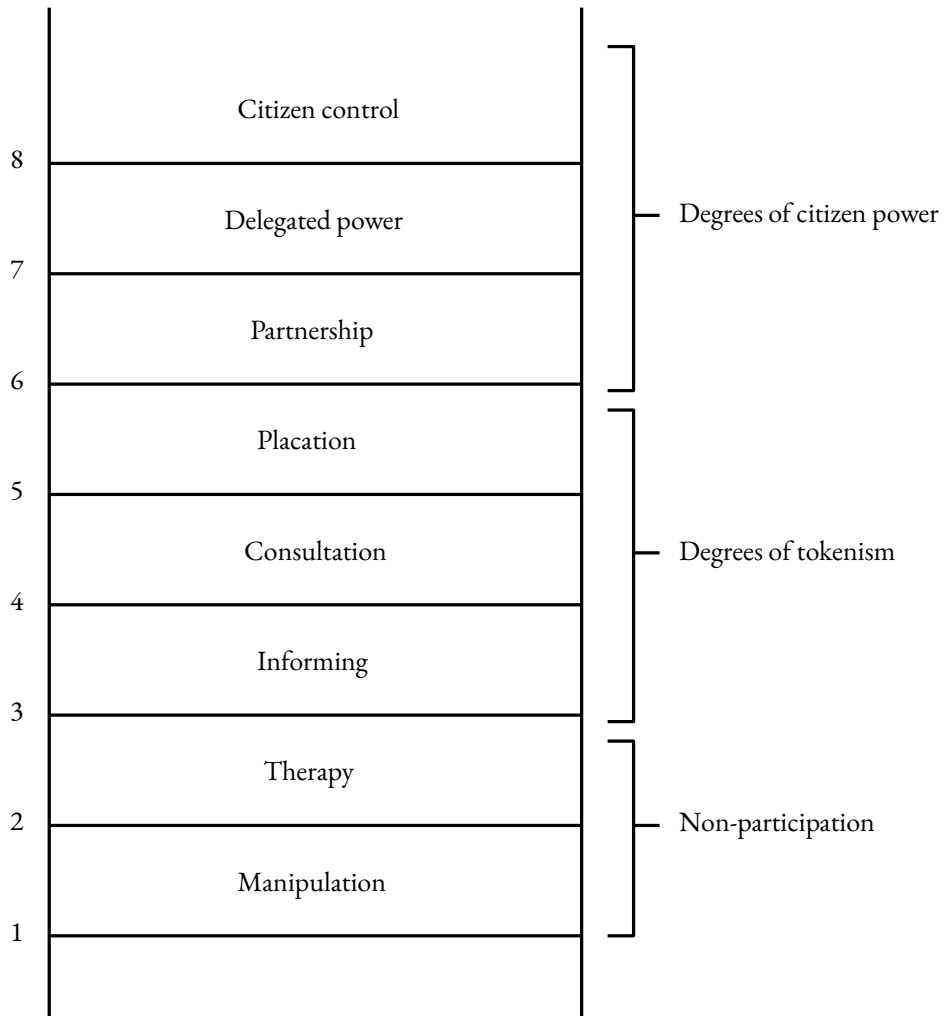


Figure 1: Eight rungs on a “ladder of citizen participation” (Arnstein, 1969), grouped into tiers reflecting increasing degrees of citizen influence in decision-making

participation are more likely to integrate immersive technologies into planning processes as a means to enhance transparency and build trust between the public and governmental bodies. Conversely, in countries with lower levels of democratic governance, participation often remains formal, and visualisation technologies are either entirely absent or used in a one-sided manner, as described by Kabrhel and Mañas (2025). Their research further explores the reasons for such one-sided manner utilisation on a case of countries represented by Singapore and China. Such countries demonstrate a very high capacity for sophisticated visualisations, while at the same time, do not represent established democracies according to the DI. In other words, state priorities in these countries often overshadow individual rights and procedural protections. This case suggests that the development of participatory methods is closely linked not only to technological factors but also to the political and institutional context (American Planning Association, 2021), i.e. to both the legislative and executive dimensions of governance, which play a critical role in shaping both the formal requirements for participation and the conditions under which such tools can be meaningfully implemented.

1.1 Objectives of the dissertation

The primary objective of this dissertation is to provide supporting research on how ICT can enhance the quality and legitimacy of spatial planning processes, encompassing phases from analytical work through proposal formulation and implementation.

Attention is given to public participation as a specific source of feedback concerning local territory. The dissertation therefore explores ICT tools that support multi-directional communication, both vertical (government-to-citizens, citizens-to-government) and horizontal channels (citizens-to-citizens). A component of the analysis involves evaluating how different visualisation technologies can simplify the presentation of complex data while simultaneously reducing barriers to engagement for diverse social groups. Another component centres on interactive visualisation and transparent data exchange, with the potential to increase participant numbers and, principally, improve the quality of their suggestions and, consequently, the quality of decision-making.

Based on given research, another objective is to develop systematic integration of collaborative ICT tools into the distinct phases of the planning cycle, considering the institutional framework of the Czech Republic. This also includes recommendations for strengthening transparency and long-term sustainability of solutions.

In conclusion, the output of this work is a set of interconnected concepts and recommendations designed to augment current practice with ICT elements possessing demonstrable potential to improve planning processes and strengthen civic engagement. These proposals are intended to serve as a basis for further research and to facilitate subsequent practical validation within the context of spatial planning; however, systematic testing and implementation of proposed measures are deferred to future endeavours.

2

Context

STANDARDISATION of spatial planning, which in recent years has been taking shape in Czechia and other European countries (European Parliament and Council, 2016, 2022, 2023, 2024), offers new opportunities not only for the planning practice itself but also for subsequent forms of analysis, presentation, and communication. These subsequent forms refer to activities that build upon the datasets originally used for spatial planning purposes. While such activities may extend beyond the field of spatial planning itself (e.g. research, policy analysis or software applications) they also rely on the availability of structured, standardised, and open-source data. The introduction of standardised technical processes and data structures, as set out through implementing decrees of legal regulations³ or methodological guidelines from the Ministry of Regional Development (*MMR*, as in *Ministerstvo pro místní rozvoj*⁴), creates a norm for consistent work with spatial planning data and documents in digital form (as explained further in chapter 2.5). This uniformity enables the creation of tools that are not tied to the specifics of individual municipalities or planners but can be applied across the entire country. When an input for spatial planning practice is standardised (i.e. uniformly structured and content-comparable data), it becomes possible

³ § 59 of Act No. 283/2021 Coll., the Building Act (as amended on March 6, 2025) further developed and detailed in § 10 of Decree No. 157/2024 Coll., on spatial analytical documents, spatial planning documentation and uniform standard (effective from July 1, 2024). However, preparations for standardisation were already initiated through amendments to the law prior to its most recent recodification in 2021, such as in § 20a of Act No. 183/2006 Coll., as amended on December 31, 2023, and further in Part 4 of Decree No. 500/2006 Coll., as amended on January 1, 2023, and the relevant annexes.

⁴ All translations of such specific legal terms will be presented in this form and are adopted from the official translation of the Building Act (Ministerstvo pro místní rozvoj ČR, 2024a).

to develop procedures and methods through which spatial plans can be effectively interpreted and presented. In this context, there is room for the development of general models or tools that leverage the potential of visualisation through virtualisation, translating planning data and documents into forms that are understandable to a broader range of stakeholders.

This approach builds on experience gained during author's collaboration with the supervisor within the international ESPON project, which focused on the Czech case study (Maier et al., 2021, 2024). The needs and limitations of current practices were identified through interviews with stakeholders in the field of spatial planning, and recommendations were subsequently developed and incorporated into the project's conclusions. One of these recommendations addressed the potential of using digital data and the need for methods that would allow for clear interpretation of such data. It became evident that for effective public participation, it is not only important what is being planned but also how the plan is presented, i.e. what forms of visualisation are used and what type of spatial experience they are able to convey.

However, this dissertation does not draw solely from the recommendations formulated within the ESPON project. Its direction is also anchored in scholarly discourse, which has been concerned with questions of participatory planning (Arnstein, 1969), digital visualisation (Jutraž & Moine, 2016), and the use of immersive technologies in decision-making processes (Han & Lee, 2023; Meenar & Kitson, 2020). A number of theoretical (Healey, 1997;

Suh & Prophet, 2018) as well as empirical studies (Birenboim et al., 2019; Harsia & Nummi, 2024) demonstrate that new technological approaches cannot be considered in isolation but must be evaluated in relation to institutional culture, data availability, land management practices, and, not least, the expectations of individual stakeholders. The literature thus provides for reflecting on what participation in the digital age entails, the role that visualisation plays within it, and both the opportunities and threats of using these tools. This is some of the theory from which the dissertation gets its approach to working with spatial data and the means of presenting spatial planning materials that improve public engagement. Ultimately, the effectiveness of participation and the likelihood of reaching agreement often hinge on the public: entrenched power groups or rhetorical individuals can delay or derail otherwise well-planned development. In these cases, well-designed visualisations might help negotiate with these actors directly or make it clearer to the wider public when opposition is primarily rhetorical.

The context of this dissertation is thus shaped both by the current institutional and technological means in the field of spatial planning and by the broader European discourse, in which issues of participation⁵ and the digital presentation of plans are becoming increasingly prominent (Nadin et al., 2021). One of the particular research projects undertaken during the preparation of this work focused on the extent and manner in which

⁵ Broader issues of participation were framed in the Aarhus Convention (UNECE, 1998), from which EU policy and legislation propagated into subsequent directives and national regulations (European Parliament and Council, 2001, 2003a, 2003b).

different countries (and their academic environments) engage with the topic of participation through the use of AR and VR reality tools (Kabrhel & Mañas, 2025). The findings indicated that the level of utilisation of these technologies often correlates with broader characteristics such as the degree of democratisation of decision-making processes (Economist Intelligence Unit, 2023) and the openness of planning cultures (Othengrafen et al., 2023; Reaver, 2023; Schneiderhan, 2018). Other projects, developed in parallel with the previously mentioned research, addressed specific possibilities for working with digital datasets related to spatial plans and their application in spatial planning practice (Mañas & Kabrhel, 2024c). Together, the aforementioned research projects (whether oriented towards mapping academic discourse or the practical application of spatial data) form the empirical and conceptual foundation upon which this dissertation builds and further develops its arguments.

2.1 Development of virtuality

The first VR device is believed to be the experimental simulator Sensorama (Heilig, 1961) as seen in figure 2 on page 18, which was a device that gave the user the experience of riding a motorcycle around New York City. In addition to visual sensations, the device also provided sounds and smells. Seven years later, the first use of AR dates back to 1968, when the first head-mounted device (HMD) for AR was developed (Sutherland, 1968). However, this device was so large that the user could not carry it on the head, so it was

suspended above the user, as seen in figure 3 on page 19. For this reason, the device was later nicknamed the “Sword of the Damocles” and this device was able to project graphics on a transparent display that blended into the real world in front of the user.

Another way to display AR is a head-up display (HUD). Similarly to the HMD, HUD is a transparent display that is placed in front of the user’s eyes and displays graphics that blend into the real world in front of the user. The difference is that while the HMD is placed on the user’s head and can be move around with the user, the HUD is placed statically in one place and can only be used when the user is in one place, e.g. a HUD that is part of a car windscreen.

The term “augmented reality” itself was first used in scientific work in the early 1990s (Caudell & Mizell, 1992). Later, medical uses began to emerge (Fuchs et al., 1996; Lavallée et al., 1995), as well as utilisation in the gaming industry (Thomas et al., 2002). The biggest increase in the use of these technologies so far has come in the new millennium. This increase has been driven primarily by further developments in technologies such as increasingly accurate geolocation, the potential of displays and 3D imaging techniques and their availability to the wider public (Allen et al., 2011). Some apps, such as the AR game “Pokémon GO”, have even reached global adoption.

In the field of spatial planning, the development of ICT has enabled new possibilities for visualising spatial changes and planning intentions, not only in terms of increasing spatial accuracy or visual quality of outputs, but also in the incorporation of additional sensory stimuli. In recent years, there has been

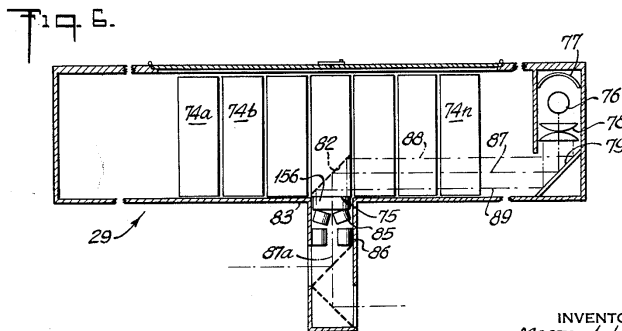
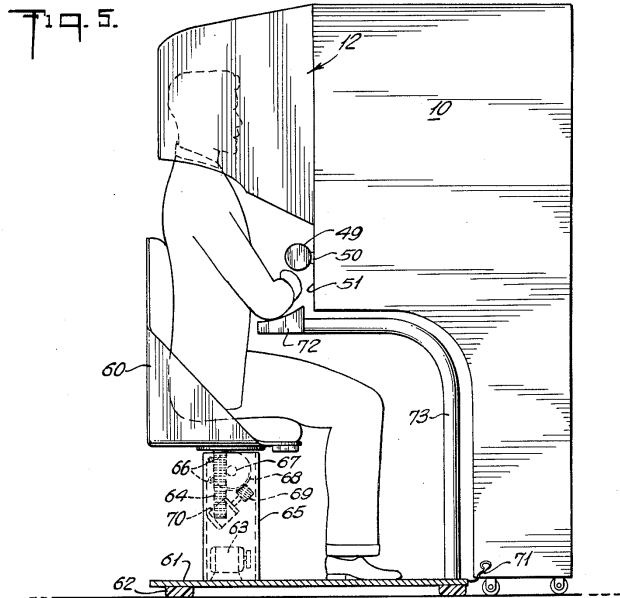
Aug. 28, 1962

M. L. HEILIG
SENSORAMA SIMULATOR

3,050,870

Filed Jan. 10, 1961

8 Sheets-Sheet 3



INVENTOR
MORTON L. HEILIG
BY
Douglas M. Clarkson
ATTORNEY

Figure 2: Depiction of Sensorama by Heilig (1961)

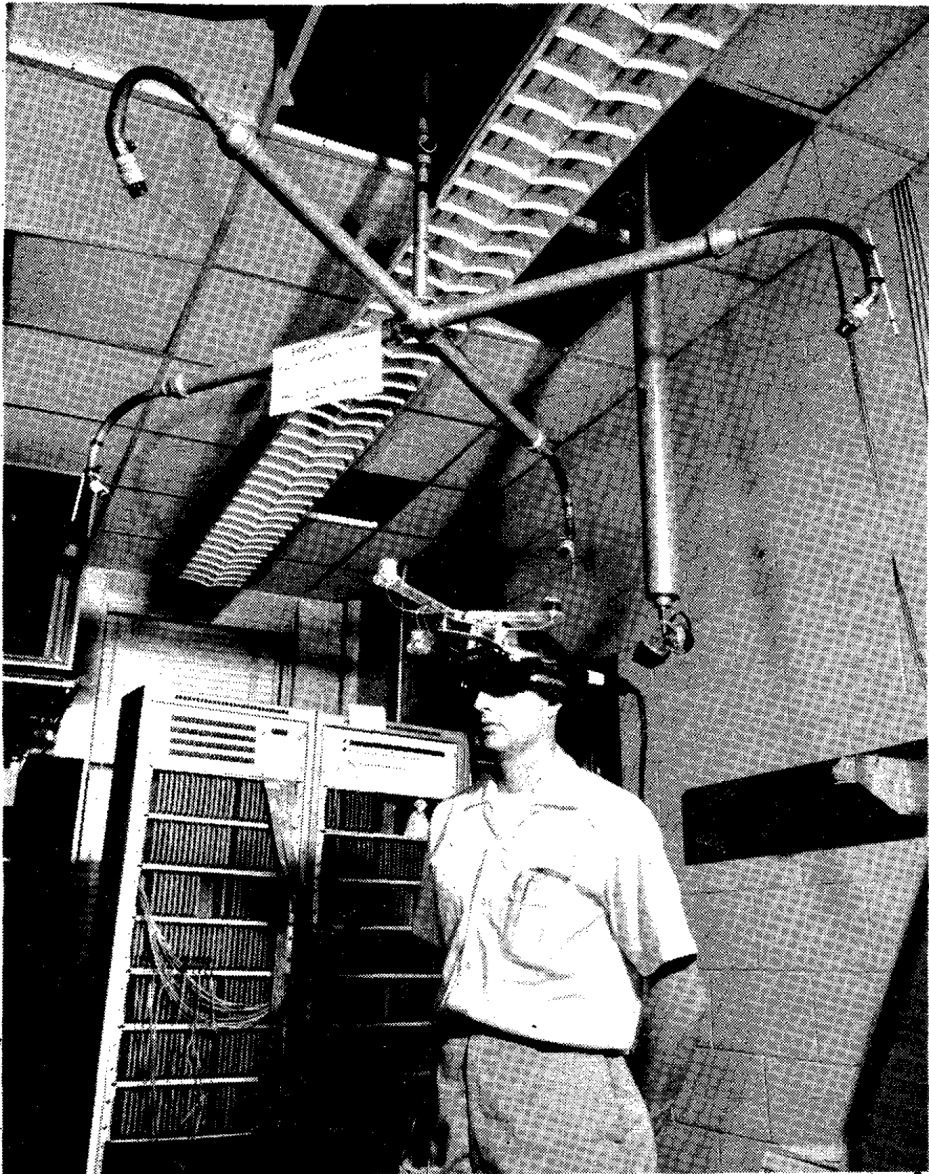


Figure 3: Depiction of an early HMD by Sutherland (1968)

growing interest in multisensory approaches (Lyu et al., 2023) that integrate auditory components into the visualisation process, e.g. through the use of auralisation⁶, i.e. a simulated reproduction of sound. Auralisation can play an important role in enhancing spatial perception, highlighting contrasting characteristics⁷ of a given area, or drawing attention to phenomena that are not easily interpretable through visual means (Jiang et al., 2018; Jo & Jeon, 2021; Schäffer et al., 2019). This trend indicates a gradual expansion in the understanding of visualisation, moving towards immersive user engagement in which the boundaries between different forms of perception and data presentation become increasingly blurred.

2.2 Terminology and fidelity of virtuality

Parallel to this technological development, a gradual dissolution of terminology and conceptual distinctions has also been observed. As the number of applications grows and technological advancement accelerates, the boundaries between the various categories of visualisation methods have become increasingly indistinct. This often results in confusion, both among professionals and the general public, regarding the correct use of terms. Similar terms such as “virtual reality”, “augmented reality”, “mixed reality” and

⁶ The term “auralisation” refers to the process of creating an audible rendering of a sound field as it would be experienced in a particular physical space. Its primary aim is to simulate and model acoustic phenomena realistically, e.g. how the outdoor environment will sound like before it is built or modified. It should not be confused with “sonification”, which involves converting data into non-speech sound to reveal abstract patterns or structures, e.g. a Geiger counter translating radiation levels into audible clicks.

⁷ Such as noisy vs. quiet zones, dense vs. sparse areas and high vs. low traffic flow.

“augmented virtuality” are frequently used interchangeably or inaccurately, not only in marketing contexts but also within academic literature. For the purposes of this dissertation, it was therefore necessary to define and standardise the core terminology, drawing on pre-established classification (Milgram & Kishino, 1994) as seen in figure 4, and extending them with considerations relevant specifically to the domain of spatial planning.

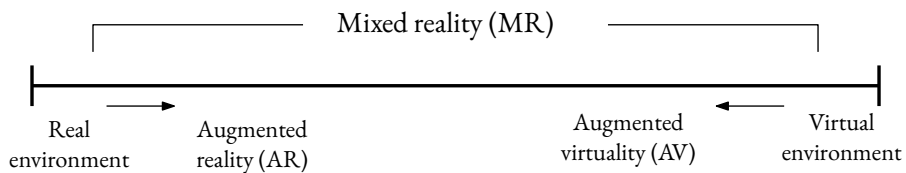


Figure 4: Reality-Virtuality continuum by Milgram and Kishino (1994)

In order to avoid ambiguities, misinterpretations, and potential terminological inaccuracies that could affect the correct understanding of the subsequent parts of the text, it is essential to first systematically define the basic terms related to the visualisation technologies used. The overarching term is the concept of extended reality (XR), see figure 5. This term refers to a set of technologies that bridge the real and digital environments. XR encompasses both virtual reality (VR) and mixed reality (MR), thereby representing the entire spectrum of possibilities for augmenting the perception of reality through digital means.

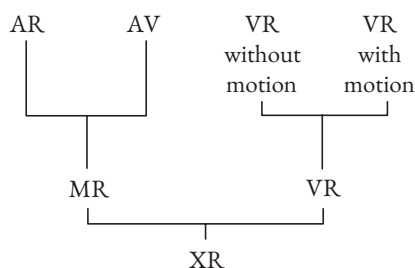


Figure 5: Hierarchy of terms concerning visualisation methods, adopted from figure 8 on page 56

MR constitutes a specific subcategory within the broader XR spectrum, encompassing technologies that enable the integration (or “blending”) of physical and virtual environments. Within MR, two primary modalities can be distinguished: augmented reality (AR), in which digital elements are superimposed onto the physical environment, and augmented virtuality (AV), where elements of the physical world are embedded within a predominantly virtual setting. These two forms occupy distinct positions along the continuum between physical reality and fully virtual environments.

The etymology of the word virtual reality in two eastern languages, known for their logograms, can help us to define the term and highlight its fundamental issue. While Japanese uses the symbol 実 (=truth) to express the concept of virtual reality i.e. 仮想現実, Chinese, on the other hand, uses the symbol 虚 (=lie) for the term virtual reality, i.e. 虚拟实境 (Ma & Choi, 2007). This dichotomy of 実 and 虚 when depicting the same term is reflecting the dual nature of virtual environments: they can be created to be perceived both as truthful representations of reality or as fabricated

illusions. This dissertation adopts a similar perspective in the context of spatial planning, arguing that different visualisation methods can present different degrees of representational fidelity. The deliberate choice of what information should be shared, kept secret or even manipulated is based on the purpose of the visualisation, which is often deeply connected to the intentions of its creator. This approach is reminiscent of Sherry Arnstein's discussion of varying levels of citizen power in the participatory process (1969), where the "truth" of participation is a spectrum from manipulation to genuine empowerment.

2.3 Participation (paradox)

Public participation in spatial planning makes up a fundamental precondition for democratic decision-making concerning the organisation and development of space. According to Horelli's definition (2002), participation enables individuals and/or groups (through the use of available tools) to become involved in various stages of the planning process and decision-making cycle⁸, thereby contributing to outcomes that are more closely aligned with their needs and interests. This approach builds upon an expanded understanding of rationality, where alongside expert knowledge, increasing value is placed on experiential, narrative, and normative forms of knowledge

⁸ The term "cycle" in this context refers to the regular electoral cycle (typically spanning four years) in which political representatives are elected. This periodicity often results in a lack of long-term continuity in decision-making, as newly elected officials may revise or abandon policies initiated by their predecessors. Moreover, as election dates approach, decision-makers may become increasingly risk-averse, avoiding unpopular or complex decisions in order to maintain public support and electoral viability.

(Forester, 1999; Healey, 1997; Sandercock, 2003). Meaningful participation, however, requires both a high level of information accessibility and a genuine opportunity to influence the resulting planning outputs.

From the perspective of planning practice, however, participation often faces challenges related to low effectiveness and a limited degree of public influence on final decisions. As noted by Innes and Booher (2018), planners and decision-making authorities (e.g. elected representatives) often question the validity of information obtained through participatory processes, particularly when such inputs diverge from expert assessments or recommendations. This tension can lead to the marginalisation of participation, which may be formally conducted yet fails to produce any substantive changes to proposed plans. To achieve effective participation, it is therefore essential not only to secure public access to decision-making processes but also to establish the necessary conditions for the representative involvement of diverse societal groups, including the selection of appropriate methods and tools (Horelli, 2002).

In recent years, there has been an ongoing transformation in the forms of public participation⁹, from traditional, physically anchored formats (such as in-person meetings and printed design proposals), to interactive digital

⁹ In Czech context, recent legislative changes have led to a narrowing of the available options for participation, effectively limiting the scope of public engagement and reducing the influence of civil society in spatial planning and environmental governance (Mañas & Maier, 2024).

platforms and environments¹⁰. XR technologies, in particular, offer novel possibilities for engaging the public with spatial planning proposals in ways that are potentially more comprehensible, spatially accurate, and visually compelling¹¹. According to Atwa et al. (2019), these technologies could work as a mediating interface between abstract planning concepts and the lived experiences of individuals. Rather than replace conventional forms of engagement, XR-enabled participation could complement and enhance them by making planning processes more inclusive (e.g. by facilitating the involvement of individuals with limited mobility or those unable to attend physical consultations).

Furthermore, simulation of spatial conditions opens new possibilities both for perceiving proposed changes and for collecting public feedback. Citizens are no longer required to interpret complex drawings or lengthy texts; instead, they can quite literally “walk through” a proposed neighbourhood or view a new building as if from the window of their own home. This form of

¹⁰ In some cities, such as Prague, the use of digital platforms for public hearings has significantly expanded, partly as a response to the COVID-19 pandemic, when physical contact needed to be limited. Public meetings were often live-streamed (e.g. from the Centre for Architecture and Metropolitan Planning, CAMP), allowing citizens to participate remotely by sending questions via online chat or calling into the studio. While in-person attendance is not excluded anymore, the digital format broadened accessibility: even after the pandemic, many of these practices have been retained, illustrating how technological infrastructure has enhanced the options for public involvement in planning processes.

¹¹ Visually compelling visualisations, while effective in capturing attention and conveying complex spatial information, may also contribute to manipulation, especially when they depict objects or environments with a level of realism that does not reflect actual or achievable conditions. Such renderings can create misleading impressions, obscuring technical limitations or uncertainties in the underlying data. This point of view is further explored within the dissertation.

“anticipatory spatial experience”, as described by Porwol et al. (2018), has the potential to enhance both public trust in the planning process and the capacity of individuals to articulate informed responses. However, it is crucial not to overestimate the capabilities of these technologies. Without clear guidelines ensuring representativeness, transparency, and openness, visualisations may function more as tools of aesthetic persuasion than as instruments of rational deliberation and genuine democratic dialogue.

Empirical evidence suggests that the success of digital participatory tools depends not only on their technical design but also on the institutional willingness to meaningfully incorporate these tools into decision-making processes. In many cases, as noted by Riedmann-Streitz et al. (2025), digital participation is reduced to symbolic gestures without any substantive influence on decision-making. Participation is thus formally fulfilled, yet empty in content. A genuine shift occurs only where digital tools are embedded within a broader strategy of open governance, i.e. one that recognises the informed citizen as a partner in the planning process, rather than a passive recipient of information.

At the same time, the issue of equitable access to digital participation cannot be overlooked. Technological infrastructure, digital literacy, and linguistic or cultural barriers significantly influence who is able to participate meaningfully and who remains excluded from the process. As noted by Blasi et al. (2022), digital forms of participation are only meaningful if they are genuinely accessible. This entails technical availability (e.g. low-threshold

platforms) and also methodological support, including facilitation and interpretation that bridge the gap between expert and lay language. Without such provisions, digital tools risk deepening existing inequalities rather than alleviating them. From the perspective of participatory planning, AR represents one of the most promising technologies, as it merges the physical and digital environments directly within the spatial context of the proposed change. This integration allows not only for the visualisation of plans at a true scale and within real-world settings, but also fosters situated understanding, i.e. the perception of the proposed development in direct relation to the everyday experiences of local users (Saßmannshausen et al., 2021). In contrast to VR, which typically immerses users in environments separated from physical reality, AR enables users to experience projected interventions within their current surroundings, significantly reducing cognitive (over)load. Additionally, individuals can engage with the environment of the proposed development directly (e.g. while walking through a street using a mobile device or smart glasses).

While VR continues to serve as a valuable tool for spatial orientation and scenario simulation (e.g. assessment of transport flows, viewsheds or shadow casting), AR technologies, due to their mobility and direct integration with the physical environment, open up new possibilities for engaging in dialogue with the public *in situ*. When combined with geolocated data and

crowdsourcing¹² approaches, they also enable real-time feedback collection, extending participation beyond the mere presentation phase into both the “pre-proposal” and “post-proposal stages”. In the pre-proposal phase, these technologies can assist in visualising alternative development options before a formal plan is drafted. In the post-proposal phase, they allow for *ex-post* evaluation of how accurately the realised project reflects what was initially presented. This is needed in cases where discrepancies arise between initially communicated project and the final realised outcomes. After meaningfully integrated (i.e. not merely as visual spectacles but as instruments of spatial orientation, comprehension, and feedback), these technologies can contribute to a shift in how the public perceives its role within the planning process.

Although public participation in spatial planning is frequently presented as a cornerstone of democratic decision-making (Forester, 1999; Healey, 1997; Sandercock, 2003), its practical implementation often encounters internal contradictions. One of the most prominent is the “participation paradox” (Reinert & Sinnig, 1997), a term that appears in scholarly literature with a range of partial or context-specific meanings. This chapter therefore aims to clarify various forms of the paradox to help readers better understand their underlying causes and implications, which can then be considered and addressed in chapter 5 of this dissertation.

¹² Crowdsourcing is the practice of obtaining input, services, or content from a large group of people, often online, rather than from traditional employees or suppliers; in spatial planning, it has been employed to gather public feedback on areas where these people live or visit, in order to compile geospatial data and to support participatory mapping initiatives. An example of such crowdsourcing app was done by Maier et al. (2015).

One interpretation of the participation paradox refers to a situation in which participation is formally mandated and supported, yet its actual influence on decision-making remains limited. This contradiction is examined by Crystal Legacy (2024), who, in the context of large-scale infrastructure projects, describes what she calls “structural gaslighting”. In her analysis, participation often functions less as a tool for collaborative decision-making and more as a procedural mechanism intended to legitimise pre-determined decisions and to mitigate conflict. The result is a paradoxical situation in which participation becomes a means of “managing dissent” rather than enabling democratic negotiation, ultimately undermining the very democratic legitimacy it was intended to enhance.

Similarly, Karic (2024), in her analysis of regional garden shows in Germany, demonstrates that public participation is frequently integrated into projects in a way that limits its effectiveness to specific, pre-defined phases and topics. The public is often involved after the most important decisions have been taken. This constrained form of participation tends to be symbolic, serving to reinforce public acceptance rather than to exert genuine influence over outcomes (Karic, 2024). Although projects often proclaim an inclusive approach, the actual practice of participation may remain shallow, technocratic, and selective; reinforcing the well-known tension between the declared and the actual citizen influence. Similarly as in the previous paragraph, the very mechanism intended to deepen democratic engagement can again end up as a legitimising ritual rather than a substantive practice.

However, this paradox is not only rooted in institutional practices but is also deeply embedded in the discourse surrounding participation itself. Klarenbeek and Weide (2020) demonstrate in their study that the discourse of participation can contain contradictory expectations, where, on one hand, participation in public affairs is perceived as desirable for strengthening democracy and social cohesion, while on the other hand, certain forms of participation, such as critical, confrontational, or those addressing inequalities, are seen as inconvenient or even undesirable, and thus regarded as a threat. In their research on integration policies in Denmark, they identify this contradiction as the “participation paradox”. Migrants, for instance, are pushed to become “active citizens”, but only if their participation aligns with the norms of the dominant discourse: “immigrant participation is both demanded and feared” (Klarenbeek & Weide, 2020). This logic creates a condition in which only certain forms of participation are accepted: typically apolitical, loyal, and conformist (see also Bloemraad & Vermeulen, 2014).

The ethical and methodological consequences of the participation paradox also manifest in the way participants are selected. Hiratsuka (2025) refers to this phenomenon as the “paradox of voluntary participation”, pointing out that when participation is entirely voluntary, the process is most often dominated by individuals with higher levels of motivation, education, competence or personal connections to the topic. However, this can lead to skewed results and a sample that is not representative. Conversely, in cases where participants are selected using a non-probability

sampling method (e.g. through snowball or quota sampling)¹³, the authentic voluntariness of participation may be weakened. Participants may feel pressured, tied to personal relationships or obligations. Therefore, research, enters into a methodological tension between inclusion and freedom, between representativeness and the ethical integrity of the process. Although often promoted as a way to enhance accessibility and openness (supporting more nuanced and inclusive outcomes), digital forms of participation do not necessarily resolve this paradox and may instead deepen it. Tools such as online platforms, voting systems, and XR technologies can inadvertently create new barriers for certain population groups due to digital inequality, language limitations or lower levels of technological literacy (Pflughoeft & Schneider, 2020). Karic (2024) similarly highlights that digital tools may enhance formal engagement; however, if they are not genuinely integrated into decision-making processes, they function merely as visualisation aids or instruments of “decorative participation”, contributing to the aesthetic presentation of planning processes without producing structural change. In this sense, Legacy (2024) warns of “visual participation”, which may obscure the lack of real influence of the public.

¹³ A statistical method “snowball sampling” involves recruiting participants through referrals from initial subjects, while “quota sampling” selects participants to reflect specific demographic criteria (e.g. age, gender).

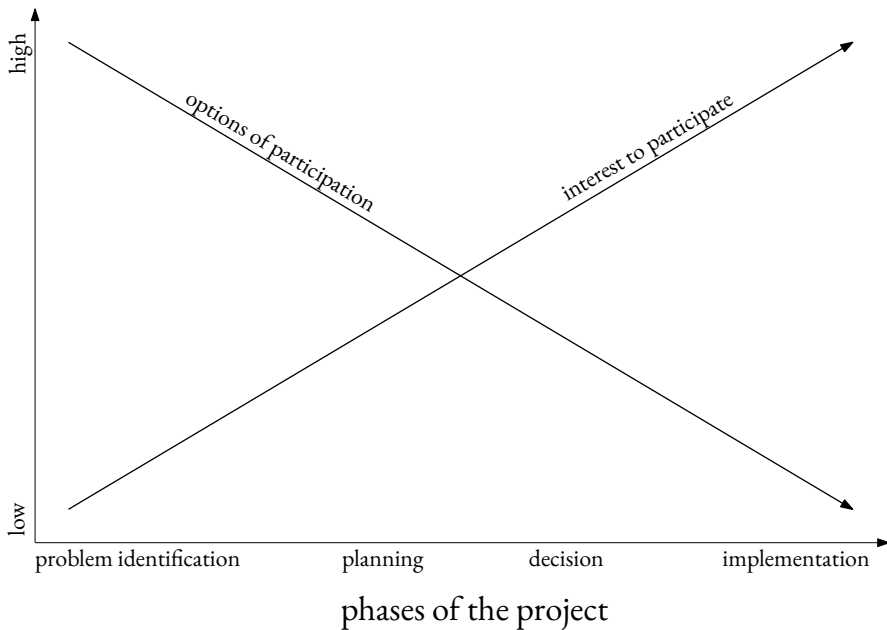


Figure 6: *Beteiligungsparadoxon*, adopted from Reinert and Sinnig (1997)

Although the participation paradox is often approached as an institutional or discursive issue, a crucial dimension of this phenomenon lies in its temporal dynamics. In German planning practice, this is referred to as the *Beteiligungsparadoxon*¹⁴ (Reinert & Sinnig, 1997), which highlights a specific mismatch between the timeline of planning processes and the interest of the public in becoming involved, see figure 6. As demonstrated by large-scale

¹⁴ The word *Beteiligungsparadoxon* can be also translated as “participation paradox”, however the German term is more specific, meaning this particular temporal form of paradox.

infrastructure projects such as Stuttgart 21¹⁵ or *Waldschlößchenbrücke*, a bridge in Dresden, citizen interest in participation tends to be low at the initial phases of the project, which is precisely at the moment when it is still possible to influence the plans in meaningful ways (Rösener, 2011; Senatsverwaltung für Stadtentwicklung und Umwelt Berlin, 2012). Over time, however, public interest increases, often peaking during the implementation phase, when the most important decisions have already been made and opportunities for change are minimal and costly. This temporal mismatch between the availability of influence and the intensity of public engagement results in a frustrating conflict, where (genuine) participation arrives too late to effect substantial change. The reasons for this are many: the protracted nature of planning processes, the complexity of administrative procedures, the lack of concrete information or the abstract nature of early-phase proposals that fail to elicit personal relevance or engagement (Hirschner, 2017). This aspect of the participation paradox underscores the need not only for structural but also procedural reforms in planning that better align with the natural rhythm and responsiveness of public interest.

As explained in this chapter, the participation paradox is thus a multi-layered phenomenon that extends beyond specific methods or technologies and reaches into the institutional logic of planning itself. Despite declarations

¹⁵ The railway and urban development project “Stuttgart 21” serves as a widely discussed case of the *Beteiligungsparadoxon*. Although large public protests and even a referendum took place, they occurred only after construction had already begun. The public backlash ultimately contributed to a major political shift: in 2009, the Green Party won the regional elections, ending the Christian Democratic Union’s uninterrupted rule over Stuttgart since 1972 (Landeszentrale für politische Bildung Baden-Württemberg, 2011).

of openness and inclusivity, participation is often confined within structures that reinforce the *status quo* and prevent any genuine redistribution of power. As the research of the aforementioned authors demonstrates, resolving this paradox cannot rely solely on technical innovations or improved facilitation; rather, it necessitates a structural rethinking of what constitutes legitimate participation, who is recognised as a relevant actor, and how input is meaningfully incorporated into final decisions.

2.4 Environmental quality of landscape

In recent years, the number of challenges influencing the environment has been increasing, whether it concerns the impacts of climate change (Gill et al., 2007; Shimoda, 2003; A. J. Smith & Goetz, 2021), the loss of biodiversity (Harrison et al., 2014) or the pressure on the landscape caused by urban development (Zýka, 2016). Spatial planning must respond to these changes not only through technical measures but also by considering the quality of the environment in which people live. In this regard, there are several fundamental topics, such as the relationship between settlements and the surrounding landscape, the extent to which they are connected or separated (Mañas & Kabrhel, 2024a, 2024b), and the ability of the landscape to fulfil both ecological (Forman & Godron, 1986; Grimm et al., 2008; Theodorou, 2022) and social functions (Carmona, 2019; Dempsey et al., 2011; Gill et al., 2007). In addition to determining the spatial allocation of development, spatial planning also addresses its implications for the everyday lives of residents, such

as urban temperatures (He et al., 2021; Jayasooriya & Adams, 2024), wind flows (Schubert et al., 2015), availability of shade and greenery or the ability of the area to retain water (Bao et al., 2019; Wang et al., 2019). The quality of these elements influences the living comfort and the health of individuals and their relationship with the place they inhabit (Fňukalová et al., 2021; Marando et al., 2022; Tiwari et al., 2021).

The increasing emphasis on environmental aspects of spatial planning is also evident in legislative documents, such as current Building Act, which explicitly incorporates elements of green infrastructure¹⁶ as an integral part of planning documentation (Mañas & Maier, 2024). This development is not incidental; rather, it reflects broader European and global trends that regard the landscape as a living system providing essential ecosystem services (such as water retention, shading, cooling of the environment, and biodiversity support), while simultaneously contributing to place identity¹⁷, mental well-being, and the engagement of residents in the planning processes.

¹⁶ Czech Republic. § 10, paragraph (1), letter (c) of Act No. 283/2021 Coll., the Building Act (as amended on March 6, 2025).

¹⁷ The concept of “place identity” (same as “place-based identity”) is derived from the meaningful and emotional connections individuals or groups form with specific geographic locations, shaped by personal experiences, social interactions, and the cultural and physical characteristics of those places. Tuan (1990) suggests that identity can become interwoven with a specific locale through the development of these positive emotional connections and a sense of belonging to that environment. This quest for identity rooted in a sense of place and belonging can be understood, in part, as a response to the broader insecurities of contemporary life where, as Bauman (2001) suggests, the ideal of a stable, supportive community is often longed for as a source of safety in an increasingly fluid and insecure world.

Notably, the concept of green-blue infrastructure¹⁸ (Almaaitah et al., 2022; Alves et al., 2019; Liu et al., 2022) helps with adaptation of cities to climate change (Anguelovski et al., 2016; Field et al., 2012; Finlay et al., 2015; Středová et al., 2015). In spatial planning, it is implemented through strategies such as increasing permeability¹⁹ (Bao et al., 2019; Barthel et al., 2017), planting trees capable of providing canopy shade, and connecting green and blue structures within settlements (Armson et al., 2012; Hsieh et al., 2016). Besides directly enhancing the capacity of urban areas to retain water and mitigate urban heat islands, these interventions also shape microclimatic conditions and contribute to the quality of public space.

The research presented in this dissertation understands the environmental context as a precondition for participatory spatial planning. Participants need to comprehend not only the spatial configuration but also the qualitative character of the environment resulting from proposed changes. The use of XR tools in spatial planning is therefore framed not merely as a means of communication, but as a medium that enables spatial and environmental imagination for fostering more informed and accessible public engagement.

¹⁸ The term “green-blue infrastructure” refers to a strategically planned network of natural and semi-natural areas that intentionally integrate nature-based elements into urban development, consisting of “green” (e.g. parks, green roofs, vegetation corridors) and “blue” components (e.g. rivers, wetlands, ponds, sustainable drainage systems).

¹⁹ The term permeability in spatial planning carries a dual meaning. Surface permeability quantifies the ratio of pervious to impervious surfaces; an important index determining the rate of rainwater infiltration and groundwater recharge (often expressed as GAR). Conversely, settlement permeability describes the possibilities for movement between a settlement and its surrounding landscape. It is not only a material property but a network-based metric, often compromised by fragmented public space, dead end streets, and unintegrated private land.

Virtual environments enable the integration of visualisations with analytical outputs derived from data on the physical characteristics of space, such as surface permeability (Mañas & Kabrhel, 2024b), built-up density (Mañas & Kabrhel, 2024c), vegetation indices or the spatial potential for new planting (Mañas et al., 2023). These datasets were analysed in selected sub-studies within this dissertation and serve as a basis for the further development of tools aimed at quantifying the ecological quality of urban space. In this context, surface permeability is understood not only as an indicator of water retention capacity, but also as a proxy for the suitability of planting higher vegetation, which can contribute to improving microclimatic conditions, reducing CO₂ emissions, and enhancing the attractiveness of the environment for residents.

By integrating spatial data, environmental indicators, and visualisation technologies, it becomes possible to create models that help the public better understand the implications of specific planning decisions. This approach helps to bridge the gap between expert-driven planning and lay perceptions of space, enhancing the quality of public feedback, an essential component of any participatory process. The environmental quality of the spaces in which people live is not only the outcome of planning decisions, but also the result of a shared value consensus, one that should be co-created through participatory engagement.

2.5 Standardisation of data and virtuality in planning

Standardised data (see the first paragraph of chapter 2) and, more specifically, environmental aspects (see chapter 2.4) intersect through virtualisation and are revealed through participation.

The potential to employ XR in this process is not determined solely by the availability of technical infrastructure or visualisation capabilities. To a significant extent, it also depends on the accessibility, quality, and standardisation of data. This is where an important interplay emerges between digital tools and the institutional and legislative recodifications that are gradually being implemented within the domain of spatial planning.

This standardisation facilitates the creation of digital territorial models that are not merely “mock-ups” for one-off presentations, but rather become long-term tools for communication, evaluation, and planning. When input data (e.g. functional land use, built-up intensity, building height levels, green elements or infrastructure) are available in a standardised format and geolocated in a precise spatial context, it becomes possible to generate not only (accurate) visualisations but also decision-support models and analyses that enable the evaluation of trends and the modelling of scenarios. Within VR environments, users can not only see the proposed change but also experience it in relation to environmental, transportation, and social interrelations.

Such capacity for data integration means it is possible to effectively visualise multiple analytical outputs, such as historical analyses, status analyses, or feasibility studies, directly within the shared virtual environment.

This offers stakeholders the ability to understand the development context, allowing them to compare proposed changes against evidence-based baselines and reach fully informed decisions.

Moreover, standardised data enable better sharing of information among various stakeholders, e.g. municipalities, regions, designers, and the public. They allow for the creation of tools that are not tied to a specific project but can be reused for different scenarios and locations. This opens the way for the systematic integration of digital technologies into participatory planning, making it not only more accessible and visually appealing but also more accurate and transparent.

Currently (y. 2025), in the field of spatial planning, standardisation is underway for spatial planning documentation (*ÚPD*, as in *územně plánovací dokumentace*) and its structure has already been stabilised. At the same time, efforts are progressing to introduce a certain degree of standardisation for the inputs of planning study (*ÚS*, as in *územní studie*) and planning analytical materials (*ÚAP*, as in *územně analytické podklady*), with a requirement that these two non-binding planning materials (*ÚPP*, as in *územně plánovací podklady*) be provided in a machine-readable format. The commitment for standardisation in the field of spatial planning is also reflected in development of additional tools, such as the Digital technical map (*DTM*, as in *Digitální technická mapa*) and the National geoportal of spatial planning (*NGÚP*, as in *Národní geoportál územního plánování*). These initiatives show the efforts at standardising, notwithstanding the inherent challenges of digitalisation.

All these (to various degrees) standardised planning documents and additional tools are very specific in the information they provide and the available datasets often vary across wider geographic areas, both in quality or date of collection, which posed challenges for the present research: relevant data had to be assembled from multiple decentralised sources, a process that introduced inconsistencies and reduced the overall accuracy of the outputs.

However, in the view of expanding the spatial planning together with the development of ICT and utilisation of visualisation technologies in spatial planning, it is important to note that these emerging methods of visualisation require new formats and standards for data and their representation. The current standardisation of spatial data in the context of Czech Republic is still in its infancy, and the existing formats are not yet fully compatible with the requirements of XR technologies. This creates a need for further development of standards that would enable the seamless integration of spatial data into virtual environments, enhancing the potential for participatory planning and decision-making, a prerequisite that is also considered when developing specific recommendations in chapter 5.

In conclusion, the ongoing efforts to standardise digital spatial planning data represent a critical and necessary step towards modernising the field. While the present research faced challenges due to the fragmented nature of existing datasets, the development of ICT and its ongoing adoption by broader public might accelerate the process of standardisation and improve public participation. In conjunction with the increasingly expanding

possibilities of spatial analysis (such as the evaluation of surface permeability (Mañas & Kabrhel, 2024b, 2024c) and the potential for tree planting or determining green coefficients (Mañas et al., 2023), as presented in chapter 2.4), virtualisation is another example of utilisation of ICT in spatial planning, enabling the development of virtual models of space not only as a communication tool but also as a platform for strategic decision-making. Standardisation here plays the role of an implicit prerequisite, a condition without which the concept of transferring planning scenarios into XR would be more difficult to implement on a broader scale.

3

Methods

METHODOLOGICAL proceeding of this dissertation is constructed as a combination of two fundamental analytical approaches: “bottom-up” and “top-down”. These two approaches are linked by their focus on the same core topic, the possibilities of utilising ICT in spatial planning, to be examined from both the perspective of local specifics and planning practices on one hand, and from a systemic, international, and structurally analytical viewpoint on the other hand. The dissertation is conceived as a monograph; however, it also builds on knowledge published in several individual scientific articles that were developed during the doctoral studies of the author and thematically complement various aspects of the main research objective.

3.1 Analytical approaches

The “bottom-up” approach was applied in this dissertation through several independent research projects conducted within the territory of Czechia. The common denominator of these studies was the focus on specific phenomena and territorial situations that represent potentially conflictual or decision-making points in planning practice, particularly in relation to the open landscape, public space, and ecological functions of the territory. One thematic focus, for example, was the surface permeability and its regulation through spatial planning, e.g. using coefficients of built-up areas and greenery (Mañas et al., 2023); another study addressed the impact of communication network planning on the continuity of landscape elements and the functional permeability of the open landscape (Mañas & Kabrhel, 2024a); a separate

3 METHODS

study analysed the impact of impermeable surfaces on ecosystem services and transitional zones (so-called ecotones) (Mañas & Kabrhel, 2024b); and another research focused on identifying landscape attractiveness from the perspective of the public and landscape aesthetics (that has been accepted but not published yet by the time of finishing this dissertation). All of these studies were conducted exclusively based on quantitative data, primarily geospatial data available from public sources²⁰, which were spatially analysed in geographic information system (GIS) and further processed statistically. Some of the findings from these studies were presented at professional conferences (Mañas & Kabrhel, 2024c), where the possibilities of transferring such acquired knowledge into the participatory phase and communication of planning intentions were discussed.

The “top-down” approach was applied in this dissertation primarily through two analytical dimensions. The first of these is a Czech case study conducted within the international ESPON project (Maier et al., 2021, 2024), in which data collection was carried out by the author and supervisor among planning actors (representatives of public administration, officials, designers)²¹ with the aim of identifying barriers and opportunities in spatial

²⁰ Several datasets were utilised, most notably The Fundamental Base of Geographic Data of the Czech Republic (*ZABAGED*, as in *Základní báze geografických dat ČR*), as well as Registry of Territorial Identification, Addresses and Real Estates (*RÚIAN*, as in *Registr územní identifikace, adres a nemovitostí*), CORINE Land Cover, Czech Statistical Office (*ČSÚ*, as in *Český statistický úřad*), OpenStreetMap etc. All datasets were accessed in their most recent available versions as of 2024.

²¹ The planning actors included 7 state officers (4 of them from regional policy unit, 2 from spatial planning unit and 1 from EU policy unit), 3 planning officers from regional offices, 2 planning practitioners and 2 research workers.

planning, some of which are associated with the use of digital tools in planning. The collected data was qualitatively processed, with the results serving as a basis for discussions during the “interactive dialogue” workshop, where numerous professionals contributed. Their discussions contributed to the formulation of recommendations that extend beyond the Czech context. The second dimension of the “top-down” approach is a bibliometric and content analysis of the professional discourse, which constitutes one of the core analyses of the dissertation. It focused on how individual countries and their academic spheres address the use of augmented and virtual reality in participatory spatial planning, and how the intensity of this interest relates to the democratic and institutional characteristics of these countries. Data was obtained from the scientific database Web of Science using a set of specific queries. The result is an overview of global developments in this field, which also provides a critical comparison of the Czech position in relation to other countries. These results were processed into a separate scientific publication (Kabrhel & Mañas, 2025) and form the interpretive basis for the subsequent sections of the dissertation.

COMBINATION of “bottom-up” and “top-down” approaches in methods of this dissertation offers both perspectives on the utilisation of ICT in spatial planning. The “bottom-up” approach, centred on specific GIS analyses and local case studies, grounds the research in practical, tangible applications. These applications show that ICT is utilised already in the preliminary phases of spatial planning process, used for gathering data, data analyses and formative data visualisations, which are also very important in spatial planning practice

(such as in the mentioned case of surface permeability). Conversely, the “top-down” approach, through the ESPON project and bibliometric analysis, provides the broader theoretical and systemic context. It shows that the ICT related issues are in the main focus of institutions (such as standardisation and digitalisation strategies of EU) and in the spatial planning practice around the world, as explored in the bibliometric study. By integrating these two perspectives, the dissertation presents a cohesive understanding of how ICT can be utilised into spatial planning, connecting on-the-ground practices with wider structural and theoretical use.

3.2 Data sources and tools

Across all individual studies, this dissertation relied on the use of quantitative data, either primary (collected through surveys and analyses within the Czech context) or secondary (sourced from scientific databases and public institutions). Main component of the research was the work with digitally structured spatial data, which reflects the current trend towards the standardisation of spatial planning and thus opens possibilities for consistent interpretation, analysis, and subsequent integration into visualisation environments. From a technical perspective, the bibliometric analysis was conducted on the data obtained from the database Web of Science, applying a methodology of quantitative bibliometrics (temporal analysis, frequency of key words, geographic distribution of authors and institutions) and thematic coding.

Furthermore, a qualitative method was employed, involving thematic coding and classification of individual studies based on the degree of participation and the degree of virtualisation. This thematic coding was developed specifically for the purposes of this dissertation, based on the possible utilisation of any given technology described in the scientific literature and subsequently tested using a combination of software tools, including QGIS, ArcGIS Pro, Python, RStudio, SketchUp, and TwinMotion, as well as hardware resources such as the Visualisation Lab²² and the Pico 4 VR headset, alongside various other open-source software and hardware platforms.

The aim of the research approach was not only the analytical processing of available data, but also the verification of whether, and in what way, it is possible to design a repeatable model for presenting (local) plans (*ÚP*, as in *územní plán*), planning studies (*ÚS*, as in *územní studie*), and other spatial planning documents at the local level, based on standardised data inputs, in a form that is spatial, comprehensible, and engaging for different groups involved in the planning process, while also remaining non-manipulative and free of private-interest bias. Here, virtualisation is not understood as a self-serving technological tool, but as a means of translating planning rules, conditions, and values into a form that fosters understanding, feedback, and informed participation.

²² The Visualisation Lab (often shortened as VisLab) is a research facility housed within the Institute of Geodesy and Geoinformation at the University of Bonn, Germany. It features a high-resolution, curved projection screen for immersive spatial visualisation, allowing for interactive VR experiences controlled via foot-based navigation. More information can be found here: <https://www.igg.uni-bonn.de/geoinfo/en/facilities>.

3.3 Methods for researching XR in spatial planning

As established in the preceding chapter 2.1, the evolution of ICT has expanded the possibilities for visualising spatial changes beyond traditional visual outputs and incorporating multisensory stimuli such as auralisation. This technological advancement has been accompanied by a parallel dissolution of conceptual and terminological distinctions within XR. The confusion surrounding terms like “virtual reality”, “augmented reality” or “mixed reality” necessitates a formal clarification to ensure accuracy and consistency.

For this reason, this dissertation first established core terminology. This was developed by drawing upon pre-established classification models, specifically the “Reality-Virtuality Continuum” by Milgram and Kishino (1994), and adapting it with additional considerations relevant to the domain of spatial planning. For the purposes of this study, a series of structured tables was developed to classify various visualisation methods according to their technological features, the degree of integration between physical and virtual environments, and the level of interactivity.

In defining these terms, attention was directed towards two dimensions: the degree of virtualisation (i.e. how far the visualisation departs from physical reality) and the degree of spatial specificity (i.e. if the visualisation must be situated in a specific geographic location). For each defined category, a representative case illustrating a real-world application was presented. This classification serves both to clarify the terminology and to provide a basis for the subsequent analytical categorisation of scholarly studies in the research.

3 METHODS

Alongside the definitions of the terms, a classification of the levels of immersion (LOIs) enabled by various visualisation methods was developed. This classification is useful for understanding the relationship between the technical solution of visualisation and its capacity to influence participation, e.g. degree of participation, understanding of the proposal, and ability to respond to it. As the LOI increases, the potential for the visualisation to draw the user into the virtual environment grows, but so does the risk of distortion, particularly if the visualisation is aesthetically or conceptually manipulative.

In the next section of the methodological approach, a quantitative analysis was conducted to examine the occurrence and qualitative topic of scholarly articles addressing the use of XR technologies in the field of spatial planning. The aim of this analysis was to test the hypothesis that the intensity of research in this domain is influenced by the political arrangement of individual countries, specifically the value of DI, as published by the Economist Intelligence Unit (2023). Related information was obtained from the Web of Science database, using a combination of the following key words: spatial planning, urban planning, spatial development, visualisation, virtual reality, augmented reality, mixed reality, extended reality and augmented virtuality. The selection of articles was limited to publications released up until 2023, and only those explicitly addressing spatial planning and presenting a certain degree of innovation or novelty were included. Articles published in predatory journals or works that merely replicated already known findings were excluded from the analysis.

Each article was associated with a country based on the affiliation of the first author (in the vast majority of cases, the articles were authored by teams from the same country). Subsequently, frequency and thematic analyses were conducted to examine the occurrence of these articles by country, with a focus on identifying correlations between the amount of research and the level of democracy in each country, as measured by the DI.

To enhance the robustness of the analysis, an additional variable was added into the study: gross domestic product (GDP) per capita according to data from FocusEconomics (2023). Since the level of economic performance of the country typically influences the funding available for research, and therefore the scope and quality of scientific output, a minimum GDP per capita threshold was set below which countries were excluded from the comparison (even if research was conducted in those countries) in order to avoid distortion due to socio-economic disparities.

ESSENTIAL part of the methodological approach was also the development of thematic coding for assessing the degree of participation and the degree of virtualisation, which enabled a consistent classification of individual studies. The degree of participation was evaluated using the eight-level scale developed by Arnstein (1969), which distinguishes between non-participation, symbolic participation, and genuine citizen influence, as seen in figure 1 on page 9. To assess the degree of virtualisation, Milgram's (1995) scale (as seen in figure 4 on page 21) was adapted and extended to eight levels: four levels of "traditional" visualisation and four levels of "extended" visualisation.

Each of the articles included in the bibliometric study was subsequently assigned to the appropriate categories within both classification schemes. In cases where it was not possible to determine a single definitive category (e.g. when the visualisation approach corresponded to multiple levels), the article was classified into all applicable categories, and weights were applied proportionally in the subsequent correlation analysis (i.e. each classification entry was assigned a fractional weight based on the total number of categories applicable to that article). This approach enabled mathematical modelling and correlation analysis to be conducted without compromising the interpretive value of the data. All calculations were performed using the RStudio environment, which proved to be the most suitable tool for this type of analysis due to its flexibility, programmability and precision.

The overall methodological approach thus integrates qualitative and quantitative approaches, employs triangulation of data sources (both empirical and bibliometric), and accounts for technological, institutional, and cultural contexts. The aim was not only to identify emerging trends in the application of XR technologies in planning but also to formulate insights that are applicable in broader settings of public decision-making; insights that may contribute to more transparent and comprehensible participatory processes in spatial planning.

4

Results

BUILDING on the terminology established in the text up to this point, the initial part of the results further deepens these definitions to avoid ambiguities and misinterpretations. This is important for facilitating a correct understanding of further findings. Therefore, to ensure clarity, the first step was to not only establish the core terminology but also to provide further differentiation, as detailed further in this chapter.

An important difference within VR environments lies in how user motion is handled. In VR without motion tracking, the user's physical position is not translated into the virtual space; instead, movement is achieved via input devices such as buttons or joysticks. Conversely, VR with motion tracking actively translates the user's real-world movements into the virtual environment. This can involve physical "walk-around" in a tracked space or utilising specialised equipment like omnidirectional treadmills that allow for continuous real-world walking motions to control movement, enhancing immersion without relying on button-based movement.

A defining characteristic of all XR visualisation methods is that rendering within these environments occurs in real time. Interactivity and immediate feedback are essential for users' perception and experience of these environments, particularly when they actively engage with the digital space via various input devices (Azuma, 1997). This capacity to deliver instant responses to user input makes XR technologies particularly well-suited for simulation, visualisation, and participatory engagement in real-world spatial planning processes, especially in gathering feedback.

As an initial part of the result, a series of structured tables was developed. These tables classify visualisation methods according to their technological features, the degree of integration between physical and virtual environments, and the level of interactivity. This classification serves not only as a tool for organising terminology but also as a basis for the subsequent categorisation of the scholarly articles analysed in one previous study (Kabrhel & Mañas, 2025). Due to its general applicability, however, this typology extends beyond the scope of this dissertation and may prove relevant in other fields such as education, industrial design, architecture, and healthcare.

Located on pages that follow, tables 1, 2, 3 and 4 define long-established visualisation methods, while tables 5, 6, 7 and 8 present increasingly virtual modern approaches, reflecting the need for robust definitions of these contemporary techniques. All tables were adopted from Kabrhel and Mañas (2025) and enhanced with additional information. Each table (from 1 to 8) is always succeeded by a figure illustrating given visualisation method being used in the context of spatial planning. Afterwards, there always is another figure, presenting the participants' perspective, which is important for understanding how the visualisation methods are perceived by users. This figure consists of two parts and follows the example as shown in figure 7. Each visualisation method is then summarised with its main pros and cons from the spatial planning perspective in several points of view, e.g. accessibility (such as easy or difficult distribution²³), fidelity, utilisation or levels of detail (LODs).

²³ Easy distribution, in this context, means relatively cheap production of copies of visualisations and their easy transportation towards participants.

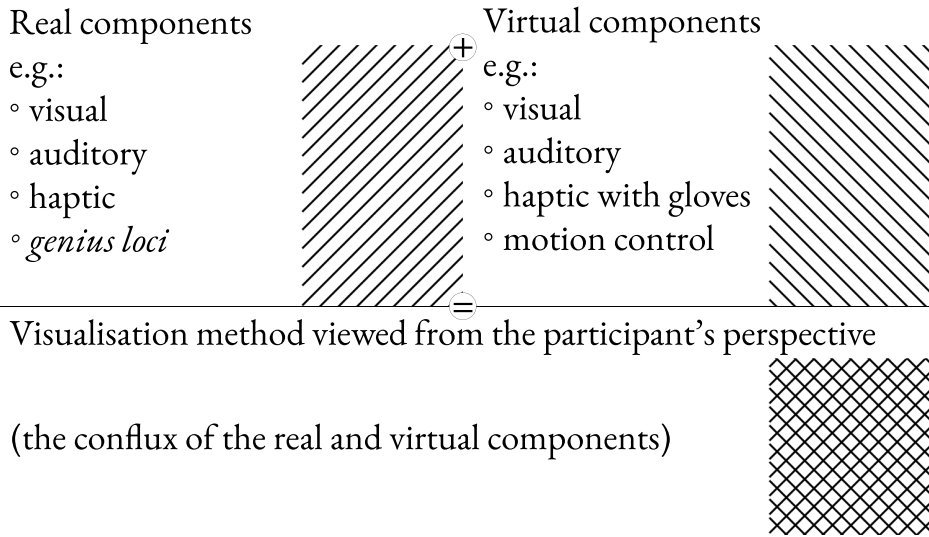


Figure 7: Illustration of presenting visualisation methods

Regarding figure 7, its upper part above the horizontal line represents the real and virtual components of the visualisation method, while the lower part of the figure below the horizontal line depicts their conflux into the participants' perspective.

THE arrangement of how the methods are presented in the following chapters also corresponds to the degree of virtuality of the visualisation method. In other words, the sooner a method is listed, the more it is based on the real environment, while the later it appears, the closer it approaches fully VR. This intentional ordering helps the reader understand that the methods discussed later represent a deeper, more immersive integration of virtuality, which, however, places a progressively higher demand on participant skill and familiarity with ICT, as well as increasing technological reliance.

4 RESULTS

This classification builds upon earlier works on Reality-Virtuality Continuum (Milgram & Colquhoun, 1999; Milgram & Kishino, 1994; Milgram et al., 1995), see figure 4 on page 21, and has been further extended with subcategories, such as VR without motion control and VR with motion control. These subcategories are then grouped into broader categories reflecting the type of virtual technology, such as the category of MR. This arrangement, based on, the degree of virtualisation is illustrated in figure 8, where the visualisation methods are organised horizontally, from left to right, according to their degree of virtualisation, ranging from less to fully virtual.

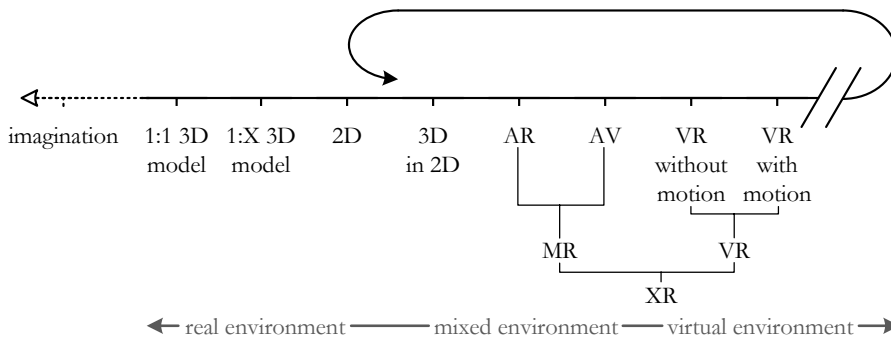


Figure 8: Visualisation methods categorised and ordered by the degree of virtualisation, adopted from (Kabrhel & Mañas, 2025)

As shown in figure 8, the degree of virtualisation indicates the extent to which a user’s sensory experience is digitally generated and mediated. A higher degree signifies a more encompassing and perceptually rich virtual environment, achieved through e.g. increasingly high-resolution and extensive displays that more fully surround users, sophisticated auralisation for realistic soundscapes, and haptic feedback to convey touch and physical interaction.

4.1 Defining traditional visualisation methods

4.1.1 1 : 1 3D model

<i>Definition</i>	The subject of this visualisation method is a physical model, a realistic full-size mock-up of the visualised object (1 : 1 scale) .	
<i>Location specificity</i>	This method is often displayed at a specific location of the visualised object (Boos et al., 2023). However, it can also be displayed anywhere else (e.g. show houses). Therefore, it is not location-specific but often is used at its location.	
<i>Example</i>	Swiss <i>Baugespann</i> , which could be translated as “construction profile”, is used to visualise the extent, volume and effect of future development using wooden or metal rods or scaffolding.	
<i>Components</i>	Real: visual, auditory, haptic, <i>genius loci</i>	Virtual: none

Table 1: Definitions of “1 : 1 3D model” visualisation method

To show this method being used in the context of spatial planning, a house in Zurich to be developed is depicted in figure 9. This method presents the future development to users of public space during their daily lives and does not require specific requirements other than spatial imagination.



Figure 9: Photo depicting how citizens of Zurich are informed through *Baugespann* of future development projects *in situ*

The same building as in figure 9 is shown again from the participants' perspective in figure 10, where the *Baugespann* is shown also on the roof.

4 RESULTS

Real components



+

Virtual components
(none)

=

1:1 3D model



Figure 10: *Baugespann* from the participants' perspective; three arrows point to the top of the poles determining the volume of future development

The main pros and cons from the spatial planning perspective:

- ⊕ **accessibility:** offers a direct real life comparison and holistic feeling of the place, inclusive to many groups of users,
fidelity: low potential for deliberate manipulation due to only real components,
- ⊖ **accessibility:** usually *in situ* only, requires spatial imagination, high cost and time to produce,
utilisation: does not visualise variants easily, only for small scale (e.g. house and smaller neighbourhood), as with increasing size, presentable LOD worsens.

4.1.2 1 : X 3D model

<i>Definition</i>	The subject of this visualisation method is a physical model, a realistic miniature or magnification of the visualised object at a specified scale (1 : X scale).	
<i>Location specificity</i>	This method is not location-specific ; it can be used anywhere.	
<i>Example</i>	A miniature model of a future development made with a 3D printer or a magnified model of a molecule.	
<i>Components</i>	Real: visual	Virtual: none

Table 2: Definitions of “1 : X 3D model” visualisation method

4 RESULTS

To show this method being used in the context of spatial planning, a model of a public space to be developed is depicted in figure 11.



Figure 11: Participant using a minified 3D model to be informed about the dimensions and proportions of future development

The same model as in figure 11 is shown again from the participants' perspective in figure 12.

4 RESULTS

Real components



+

Virtual components
(none)

=

1:X 3D model



Figure 12: 3D model of future development shown from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **accessibility:** easy distribution, traditional and long-used, offers spatial configuration and view axes,
utilisation: can be used to visualise variants, for every scale, especially usable in larger scale,
- ⊖ **fidelity:** does not imply context that can be omitted, loss of human scale (although a camera can be put into the model to imitate a human perspective, resulting in a different visualisation method).

4.1.3 2D

<i>Definition</i>	Visualisation of a 2D model in a 2D environment. The physical world is not the subject of the visualisation, but an object to which the 2D model is projected using either digital (e.g. screen) or physical (e.g. paper) means.	
<i>Location specificity</i>	This method is not location-specific ; it can be used anywhere.	
<i>Example</i>	A floor plan minified at a scale of 1 : 5 000 and visualised on paper, or a magnified model of a protein cross-section at a scale of 1 000 : 1 visualised on a computer screen.	
<i>Components</i>	Real: directly visual or mediated via screen	Virtual: none or visual via screen

Table 3: Definitions of “2D” visualisation method

4 RESULTS

To show this method being used in the context of spatial planning, a 2D map of a public space to be developed is depicted in figure 13.

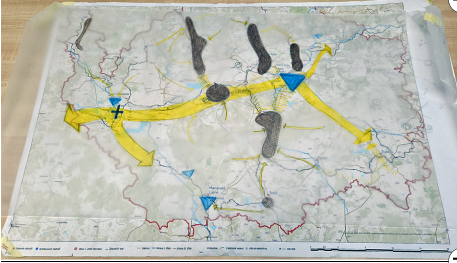


Figure 13: Participant using a 2D map with a conceptual overlay to be informed about an area of interest

The same map as in figure 13 is shown again from the participants' perspective in figure 14.

4 RESULTS

Real components



+ Virtual components
(none)

2D

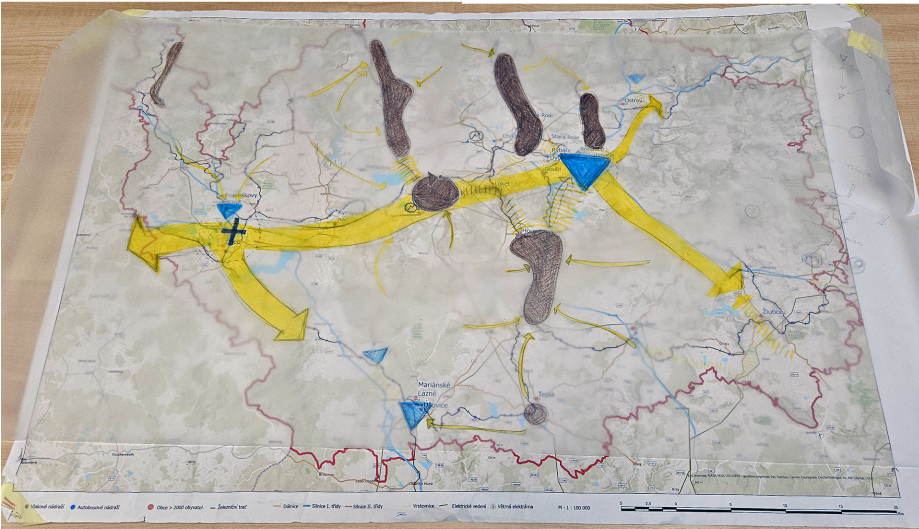


Figure 14: 2D paper map with a conceptual overlay shown from the participants' perspective

In the case of 2D, it is a transitional method, which can be visualised using both real and virtual media. As an example of the real media, a paper 2D map was shown in figures 13 and 14. However, any 2D map can be also visualised virtually, using a screen of any kind, as shown in figure 15, where the participant is viewing a map on a multitouch screen.

4 RESULTS

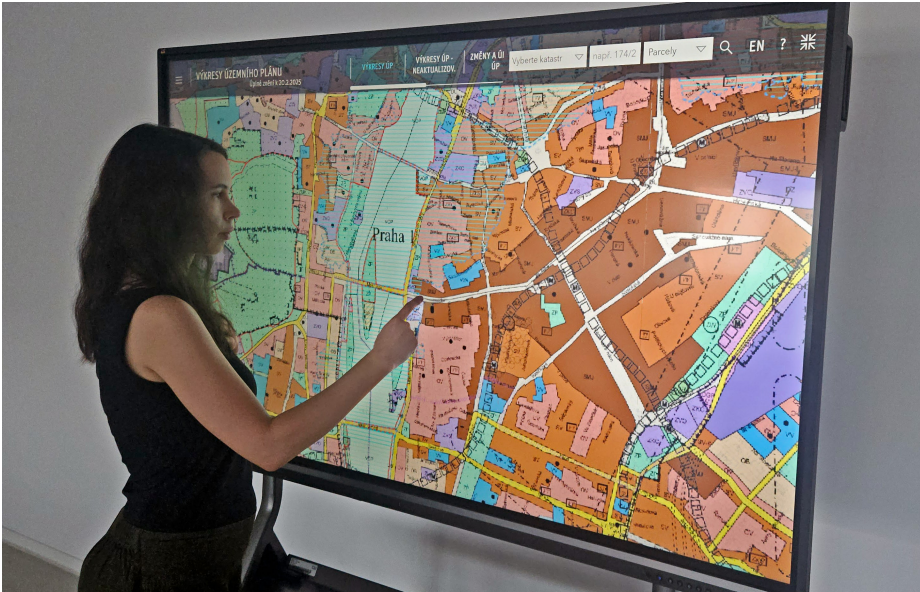


Figure 15: Participant using a multitouch screen to view a 2D map informing them about the dimensions and proportions of the public space to be developed

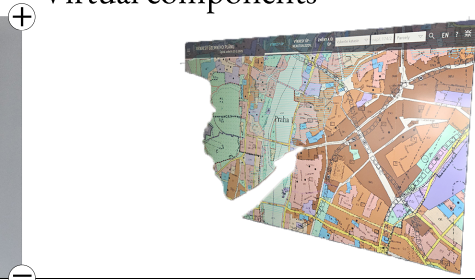
The same map as in figure 15 is shown again from the participants' perspective in figure 16.

4 RESULTS

Real components



Virtual components



2D

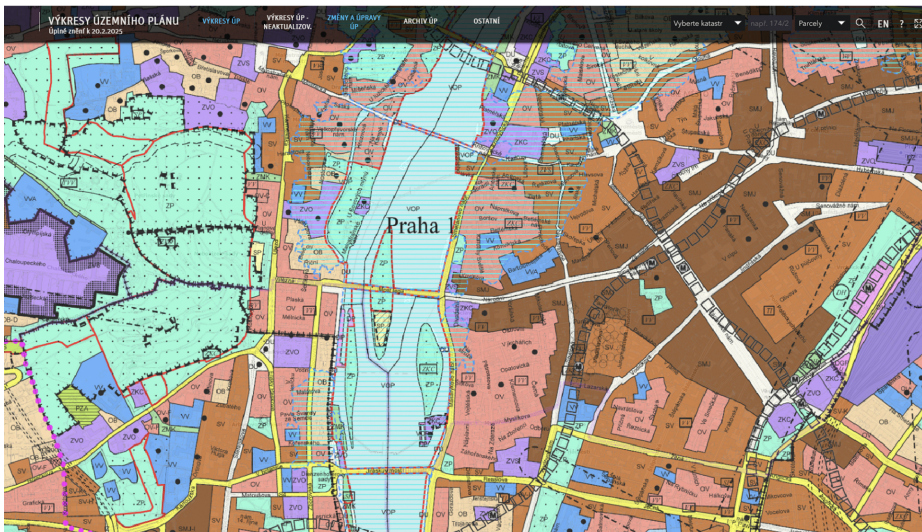


Figure 16: 2D map shown on a multitouch screen from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **accessibility:** easy distribution, traditional and long-used, inclusive to many groups of users, low development and reproduction costs, **utilisation:** for every scale, when correct LODs are used, suitable for wide range of objects,
- ⊖ **accessibility:** additional information (e.g. FAR, GAR, height limit and transportation) might be difficult to understand for lay public, requires cartographic literacy, **fidelity:** depends on representation, standardisation and LODs, lack of volumetric perspective.

4.1.4 3D in 2D

<i>Definition</i>	Visualisation of a 3D model in a 2D environment, thus adding plasticity. It can be displayed by various means of graphical projection (e.g. axonometric, perspective). The physical world is not the subject of the visualisation, but an object to which the model is projected using either digital (e.g. screen) or physical (e.g. paper) means.	
<i>Location specificity</i>	This method is not location-specific ; it can be used anywhere.	
<i>Example</i>	A minified version of a building at a scale of 1 : 100 visualised on a computer screen using perspective for the 3D effect.	
<i>Components</i>	Real: directly visual or mediated via screen	Virtual: none or visual via screen

Table 4: Definitions of “3D in 2D” visualisation method

To show this method being used in the context of spatial planning, a model of a public space to be developed is depicted in figure 17.



Figure 17: Participant studying a minified 3D model to be informed about the dimensions and proportions of future development

The same model as in figure 17 is shown again from the participants' perspective in figure 18.

4 RESULTS

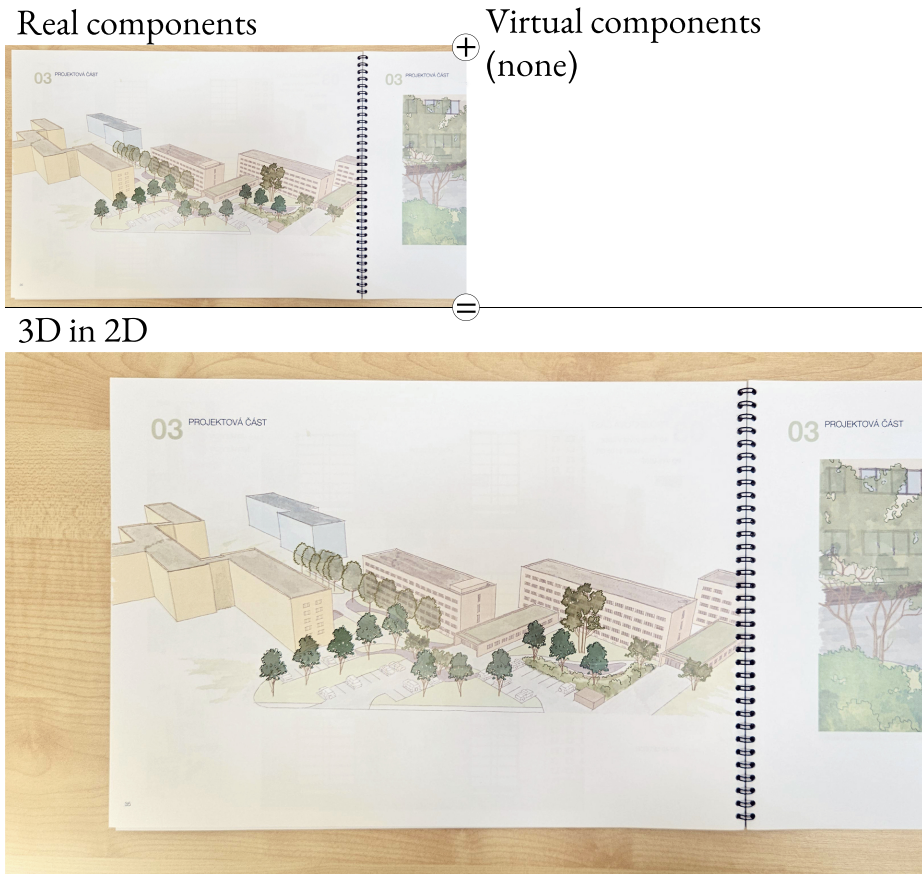


Figure 18: 3D model shown on paper from the participants' perspective

Same as previously mentioned 2D visualisation method, the 3D in 2D visualisation method is the transitional method, which can be visualised using both real and virtual media. As an example of the real media, a printed 3D visualisation was shown in figures 17 and 18. However, any 3D visualisation can be also visualised virtually, using a screen of any kind, as shown in figure 19, where the participant is viewing a 3D visualisation on a multitouch screen.



Figure 19: Participant using a 2D multitouch screen to view a 3D visualisation informing them about the dimensions and proportions of the public space to be developed

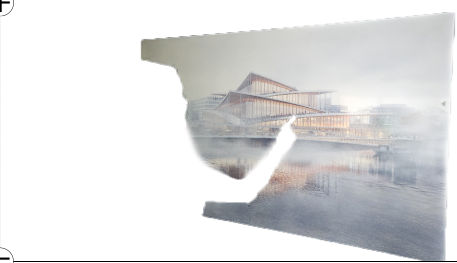
The same visualisation as in figure 19 is shown again from the participants' perspective in figure 20.

4 RESULTS

Real components



Virtual components



3D in 2D



Figure 20: 3D visualisation depicted on 2D multitouch screen shown from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **accessibility:** easy distribution, commonly used, inclusive and intuitive to many groups of users,
- ⊕ **accessibility:** cost depends very much on LOD,
- ⊖ **fidelity:** depends even more in comparison with previous method on graphic representation, standardisation and LODs, as it offers more means for manipulation, such as lighting or masking that can limit comprehensive spatial understanding.

HAVING systematically reviewed the traditional means of visualisation, a transition is now made to an examination of contemporary visualisation methods. This subsequent section with methods extending reality, specifically those utilising ICT to either augment or entirely generate the visual environment, thereby addressing the limitations inherent in their predecessors, but also having greater potential for manipulation and increased reliance on technology.

4.2 Defining extended visualisation methods

4.2.1 Augmented reality (AR)

<i>Definition</i>	This method introduces a virtual subject that is visualised using ICT and this virtual element is overlaid onto the real world. On the reality-virtuality continuum, it is located nearer “reality” end of the spectrum.	
<i>Location specificity</i>	This method is bound to the real environment, meaning that it is location-specific . Therefore, the real component is fundamental to the visualisation and it cannot be displayed anywhere else.	
<i>Example</i>	A mobile phone screen to which live footage from the phone camera is projected and enriched with a virtually visualised subject. HMD or HUD, which are transparent by default, are additional examples.	
<i>Components</i>	Real: visual, auditory, <i>genius loci</i>	Virtual: visual, auditory

Table 5: Definitions of “AR” visualisation method

This method is special, because it requires the user to be present at the location of the visualised object. In figure 21, participant utilises AR technology and elements of the virtual world are incorporated into a predominantly real scene.

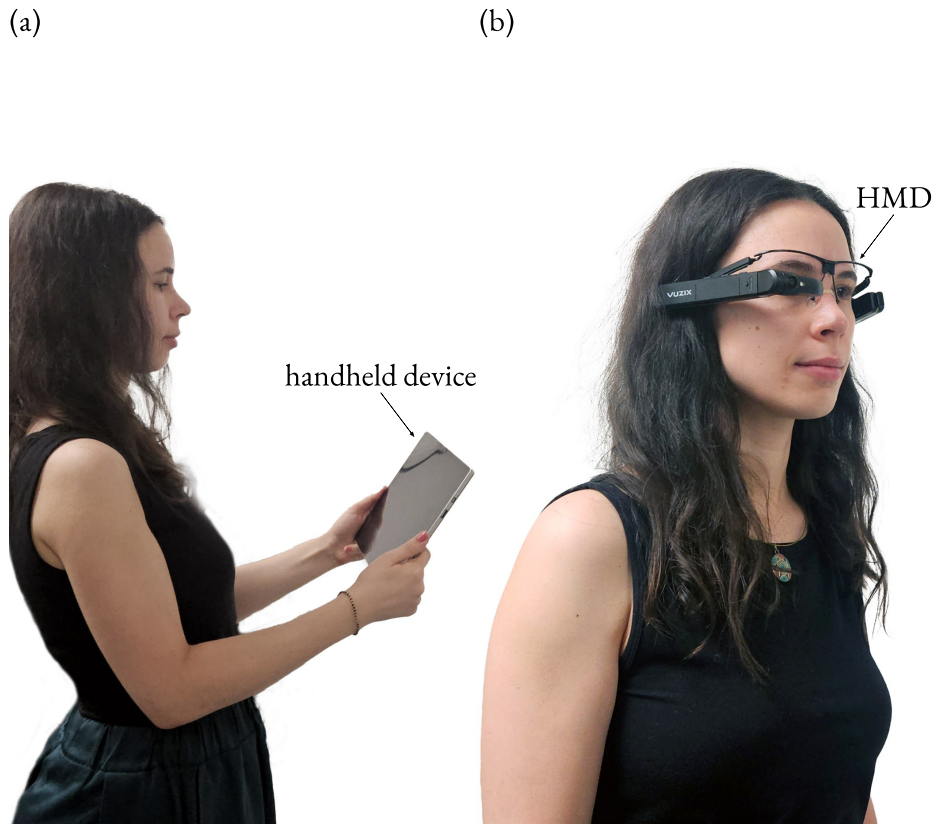


Figure 21: Participant using AR in the form of (a) handheld device (tablet) with pass-through enabled (see chapter 4.3.1) and (b) HMD

The same visualisation as in figure 21 is shown again from the participants' perspective in figure 22.

4 RESULTS

Real components



Virtual components



Augmented reality (AR)



Figure 22: Utilisation of AR from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **accessibility:** easy to view on common handheld devices, relatively easy and cheap production of copies of the visualisation, the real component provides familiarity for users,
utilisation: variants (e.g. of the proposed development) are visualised easily,
fidelity: the real component provides context and induces a sense of *genius loci*,
- ⊕ **fidelity:** virtual component is prone for manipulation, while in counteraction, the real component provides context grounded in reality,
- ⊖ **accessibility:** *in situ* only, expensive production of models, excludes less technical groups of users (but both disadvantages might change soon due to scientific advancements),
utilisation: only for small scale (e.g. house and smaller neighbourhood), as with increasing size, presentable LOD worsens.

4.2.2 Augmented virtuality (AV)

<i>Definition</i>	This method introduces a real subject that is visualised using ICT and this real (but virtualised) element is merged into the virtual world. On the reality-virtuality continuum, it is located nearer “virtuality” end of the spectrum.	
<i>Location specificity</i>	This method is not location-specific . Interaction between users revolves around the virtual world. Therefore, the virtual component is fundamental to the visualisation and it can be displayed anywhere.	
<i>Example</i>	A live feed of another person is projected inside a virtual environment, which can be shared by more people, using any flat surface as a proxy upon which any virtual image can be projected and interacted with. Such a surface could be formed e.g. by a paper map laying on a table with 3D models projected on it to represent buildings.	
<i>Components</i>	Real: not relevant	Virtual: visual, auditory

Table 6: Definitions of “AV” visualisation method

To show this method being used in the context of spatial planning, figure 23 illustrates a participant utilising AV technology within an indoor environment. Here, elements of the physical world are incorporated into a predominantly virtual scene.



Figure 23: Participant using AV in a room

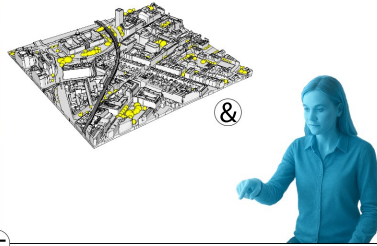
The same visualisation as in Figure 23 is shown again from the participant's perspective in Figure 24. Consistent with the nature of AV, this scene illustrates the superimposition of a real component (i.e. a live-feed representation of another person seen in blue) onto the mutual virtual collaborative environment. A HMD is utilised in the illustration, however use of a handheld device with pass-through enabled (see chapter 4.3.1) remains possible, although less frequent and less convenient in this context.

4 RESULTS

Real components



Virtual components



Augmented virtuality (AV)



Figure 24: Utilisation of AV in a room from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **accessibility:** relatively easy and cheap production of copies of the visualisation,
utilisation: variants are visualised easily, possible for every scale, where larger area requires lower LOD (higher abstraction),
- ⊖ **accessibility:** expensive, excludes less technical groups of users (both disadvantages are more profound for AV methods in comparison with AR method),
fidelity: lack of real component, where virtual component is prone for manipulation.

4.2.3 Virtual reality (VR) without motion control

<i>Definition</i>	A completely virtual model visualised within a virtual environment. Reality is entirely obscured from the viewer (usually with opaque glasses), although, with pass-through enabled (see chapter 4.3.1), the image of the real world can be registered by the device’s camera and mediated to the user through the device’s display. Motion control using gestures is not possible in this method. It is only possible with an additional input device (e.g. gamepad, mouse or keyboard).	
<i>Location specificity</i>	This method is not location-specific ; it can be used anywhere.	
<i>Example</i>	Using VR glasses to visualise different designs of urban space and controlled via a hand controller.	
<i>Components</i>	Real: none	Virtual: visual, auditory

Table 7: Definitions of “VR without motion control” visualisation method

To show this method being used in the context of spatial planning, figure 25 illustrates a participant utilising VR technology, wearing fully opaque headset. Here, only virtual components form the participants’ experience.



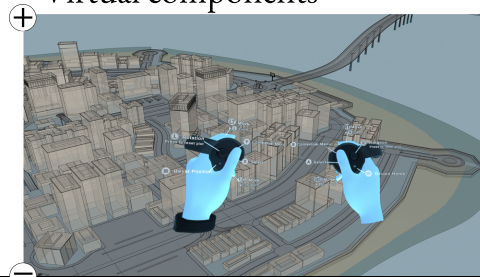
Figure 25: Participant using VR headset in a room

From the participants' perspective, the visualisation can be seen as is shown in figure 26 below.

4 RESULTS

Real components
(none)

Virtual components



Virtual reality (VR) without motion

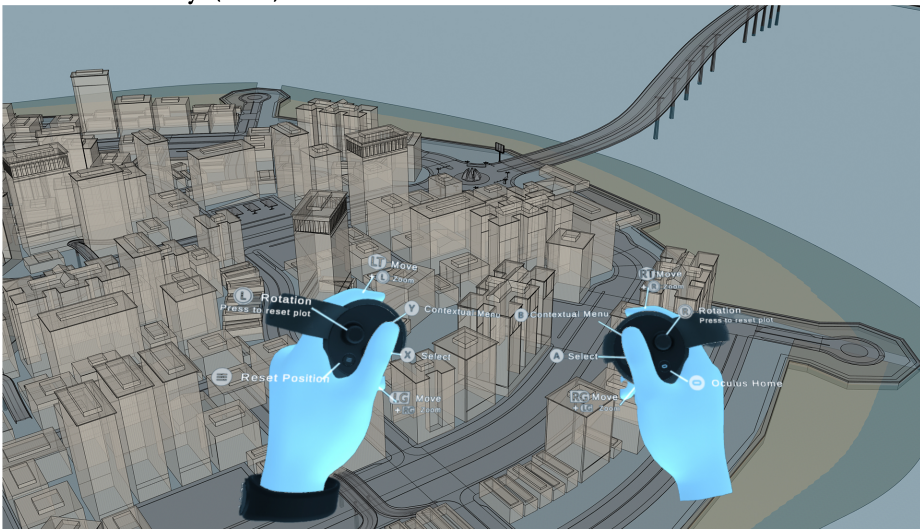


Figure 26: Utilisation of VR without motion control from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **utilisation:** variants are visualised easily, possible for every scale, where larger area requires lower LOD (i.e. higher abstraction), in order to keep amount of presented information manageable and prevent sensory overload,
 - ⊖ **accessibility:** expensive, excludes less technical groups of users (both disadvantages are more profound for VR methods in comparison with MR methods), dependence on external input devices (e.g. controller or keyboard),
- fidelity:** it is easier to lose human scale (e.g. when zoomed out and using only buttons), lack of real component, virtual component is prone for manipulation (again, more considerable than the XR methods).

4.2.4 Virtual reality (VR) with motion control

<i>Definition</i>	A completely virtual model visualised within a virtual environment. Reality is entirely obscured from the viewer (usually with opaque glasses), although, with pass-through enabled (see chapter 4.3.1), the image of the real world can be registered by the device's camera and mediated to the user by the device's display. Motion control using gestures, such as walking or grabbing, is possible, adding more immersion.	
<i>Location specificity</i>	This method is not location-specific ; it can be used anywhere.	
<i>Example</i>	A set of VR glasses and a motion detector, physical (e.g. trainer) or digital (e.g. camera).	
<i>Components</i>	Real: none	Virtual: visual, auditory, motion control, haptic (with gloves on)

Table 8: Definitions of “VR with motion control” visualisation method

To show this method being used in the context of spatial planning, figure 27 illustrates a participant utilising VR technology, wearing fully opaque headset and standing in a motion control station. Here, only virtual components form the participants' experience.

4 RESULTS



Figure 27: Participant using VR headset in a room, standing in a motion control station, (a) bare handed and (b) wearing haptic feedback device

From the participants' perspective, the visualisation can be seen as is shown in figure 28 below.

4 RESULTS

Real components
(none)

Virtual components
+



Virtual reality (VR) with motion
=



Figure 28: Utilisation of VR with motion control from the participants' perspective

The main pros and cons from the spatial planning perspective:

- ⊕ **fidelity:** better understanding of the space in comparison with the previous method,
utilisation: variants are visualised easily, allows for highly intuitive and natural interaction, ideal for capturing both conscious and subconscious feedback (especially with the simultaneous utilisation of eye tracking)
- ⊖ **accessibility:** expensive, excludes less technical groups of users (both disadvantages are most considerable in comparison with all other methods), high liability for nausea when calibrated incorrectly,
fidelity: lack of real component, where virtual component is prone for manipulation (again, more considerable than the XR methods),
utilisation: only smaller scale is walkable, but this can be solved with “teleport” within the model.

4.3 Defining additional terms and relations

4.3.1 See-through and pass-through

When defining the AR and VR methods in the previous chapters, an important distinction is made in how these XR systems mediate the real world to their users. In case of VR, the real environment is captured by outward-facing cameras and re-rendered on a screen within the headset, where it can be augmented with digital elements. This mode is called “pass-through”.

This differs fundamentally from “see-through” systems, commonly used in AR, where semi-transparent displays allow digital content to be overlaid directly onto the user’s direct view of the physical world.

The main difference lies in the mediation of reality: see-through systems preserve an unfiltered visual connection to the world, with digital content added atop transparent optics; pass-through, on the other hand, interposes a layer of digital reconstruction between the user and their surroundings, offering an integrated view that blends real and virtual inputs in a single feed, providing a mediated view.

4.3.2 Nested virtualisation

The looping arrow in figure 8 on page 56 represents an intriguing situation where a visualisation method with a higher degree of virtualisation contains, or embeds, another visualisation method, much like a larger Matryoshka doll contains a smaller one. This structure parallels a concept in computer software known as nested virtualisation (Zhang et al., 2011), where virtual machines can be run inside other virtual machines, creating a recursive, layered system. This recursive quality can create feedback loops where one visual layer frames another, nesting representations within representations.

An exemplary scenario might involve a user wearing a VR headset with passthrough enabled while viewing a map on their smartphone. In this case, the headset renders a virtual view of the real-world smartphone, which in turn is rendering a digital map, creating a visualisation within a visualisation.

What is interesting here is not just the technological recursion, but the shifting frames of presence and interpretation. Each layer mediates the next, creating a stack of perspectives, each real in its own way, with a higher degree of virtualisation, but also dependent on the frame that contains it. Although performance issues like latency may currently hinder this experience, such limitations are expected to diminish with technological advances.

4.4 Opening mind towards future technology

With the continuous advancements in ICT, the ability to create highly realistic virtual worlds is rapidly increasing, particularly with the development of more powerful graphics cards, advanced sensors, and faster data processing. Future technological advancements are expressed using this symbol: // on the horizontal axis in figure 8 on page 56. And as a result of these advancements, the need to rely on imagination when perceiving visualisations is gradually diminishing. The digitally created environment becomes so convincing that individuals increasingly perceive it as real. In other words, the distinction between what is real and what is virtual is increasingly blurred.

However, this does not mean that a higher degree of virtualisation always results in a more accurate or faithful representation of the real world. It is possible to create entirely fictional worlds, which, thanks to their high degree of virtualisation, may be perceived as highly vivid and “real” (e.g. a virtual world that feels real due to realistic lighting, sounds or physics, even though it does not correspond to any existing location).

On the other hand, when high degree of virtualisation is used to make visualisation as closely aligned with the real environment as possible, it creates a very faithful and convincing experience, which is necessary in a range of fields where it is important for users to have an environment that closely resembles reality, including realistic visuals, interactions, and the environment's reactions to human stimuli, such as military training (Wahyudi & Infantono, 2017), construction, or medicine (Furman & Hsu, 2021; McKnight et al., 2020; Müller et al., 2020; Stromberga et al., 2021; Torous et al., 2021; Uddin et al., 2021); for more examples, see chapter 1.

Future developments in XR could allow for sensory manipulation, where devices such as brain-computer interfaces induce feelings about a place, e.g. warmth or openness on one hand and danger or crowdedness on the other hand. Such capabilities would mark a new stage of immersion, which is potentially even more prone to manipulation. This raises important ethical considerations beyond planning practice that future research should focus on, see chapter 4.7.

In the field of spatial planning, the credibility of visualisations enabling better public understanding and feedback is linked to the degree of public participation. In this sense, authentic visualisation can be connected to the concept of the ladder of participation, as formulated by Arnstein (1969) and further developed by Choguill (1996). When visualisations are realistic, transparent, and appropriately utilised, the risk of their misuse for manipulation at lower degrees of participation can be reduced.

4.5 Increasing immersion via multisensory involvement

As noted earlier, a higher degree of virtualisation does not automatically mean a more accurate depiction of reality as it may also refer to fictional or stylised environments. However, this degree is closely related to another important concept: immersion, or the extent to which a user feels they have “entered” the visualised environment. The conceptual model presented here differentiates between two forms: direct immersion and mediated immersion. Direct immersion is the experience of the physical world through unassisted human senses; for example, seeing a building with own eyes or feeling the texture of a model with own hands. In contrast, mediated immersion involves stimuli that are virtualised and delivered to the senses via a technological apparatus, such as a computer monitor, XR headset or haptic gloves.

This relationship is further explored in the following section and illustrated in figure 29. Although human perception involves five senses, two of them (taste and smell) are not considered here, as they operate on a chemical basis and have a completely different nature in the context of XR visualisations (S. Smith et al., 1998). Another issue to be noted is that the line depicted in the figure represents the potential level of immersion, not the actual level achieved. It illustrates the maximum capacity of a given visualisation method.

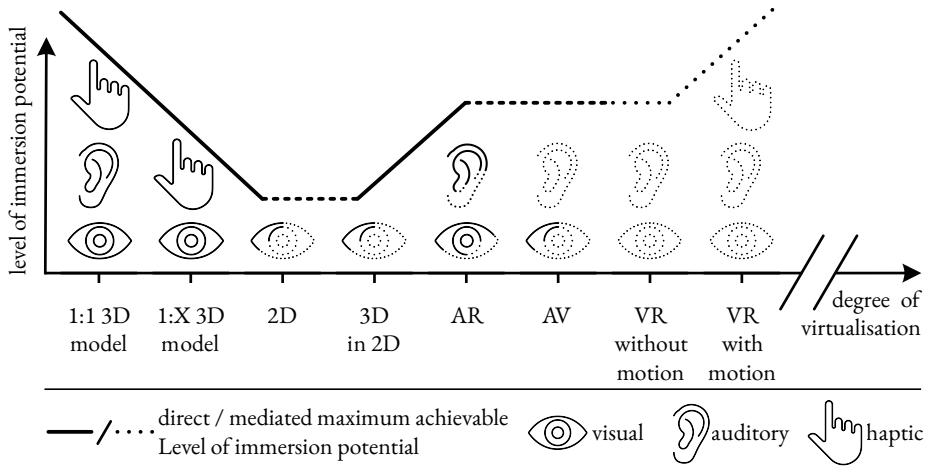


Figure 29: Association between the increasing degree of virtualisation and LOI (Kabrhel & Mañas, 2025); the order of the x-axis is retained, as shown in figure 8 on page 56

4.6 Further results

Building on these findings, the next phase of the research examines how different forms of visualisation of future development may influence public responses within participatory planning processes. The study is performed in cooperation with Bonn University, specifically the Institute of Geodesy and Geoinformation and it explores this relationship through various indicators. Detailed procedures, criteria and evaluation results will be presented in a subsequent publication.

In parallel with the research in cooperation with Bonn, another work has begun on developing an experimental AR application. This tool is intended to enable users to view proposed variants of future development directly

within their physical surroundings and to contribute their own suggestions or modifications to public space based on individual preferences and needs. The application is designed to run on newly acquired XR hardware and will serve both as a research instrument and as a pilot demonstration of participatory AR methods in spatial planning. Details of its design and implementation will be presented in subsequent publications once testing and validation are complete.

4.7 Future research

Several areas of future research can be identified that extend beyond the scope of this dissertation but emerge logically from its findings. These directions are outlined below as potential themes rather than concrete proposals.

A first theme concerns anticipated advances in immersive display and control technologies. As previously mentioned in chapter 4.4, research into brain-computer interfaces (Rafferty, 2021) indicates that future systems may bypass conventional input devices and deliver visual or affective content directly to the user. These interfaces would operate without hardware such as joysticks or other physical controllers. For spatial planning, such developments could allow the transmission not only of visual and acoustic qualities of place but also of subjective attributes such as *genius loci*, perceived safety, crowding, or local atmosphere. This raises fundamental ethical questions regarding interpretation, consent, and the potential for manipulation in participatory processes.

A second direction relates to the use of immersive technologies in professional training and higher education. Previous work has shown their value in supporting experiential learning and complex spatial reasoning (Radianti et al., 2020). Applying these methods to educational programs in spatial planning could improve understanding of site-specific constraints and opportunities, better preparing graduates for participatory design tasks. While some utilisation of these technologies exists in paedagogy, it is not yet widespread and warrants systematic investigation.

Finally, rapid advances in AI generated visualisations require critical examination. AI tools already produce photorealistic renderings and automate modelling tasks with minimal human input (Batty, 2024). While these tools may increase efficiency, they also pose risks of biased or persuasive representations. Further research should address governance and transparency mechanisms to ensure their responsible application in participatory planning.

5

Recommendations

RECOMMENDATIONS for the design of planning processes are based on the findings of the previous chapters. They are specifically intended to help designers, researchers, and practitioners in creating effective and truly inclusive processes in planning. The recommendations are structured around the main themes that clearly emerged from the analysis of the planning practice and its challenges.

These recommendations aim to enhance the existing planning processes in Czechia by broadening their scope and application, rather than introducing entirely new procedures, which could lead to confusion and unnecessary complexity. The recommendations are applicable not only to legally binding spatial planning documentation but also to non-binding strategic planning documents, such as planning studies (*ÚS*)²⁴. The use of advanced ICT and visualisation methods can help the public better understand the issues within an area and, consequently, submit more relevant questions or requirements for its development.

Moreover, with XR technologies, the public can gain a deeper overall insight into the challenges and opportunities visualised in non-binding planning documents. This enhanced comprehension, achieved through greater immersion, may significantly increase public understanding of these

²⁴ Since planning studies are not created for the entire territory of Czechia (as the law cannot enforce this), they do not exist at the municipality level for the whole country. In contrast, the other non-binding documents, the planning analytical materials (*ÚAP*), are legally required across the entire territory of Czechia. However, if these documents become standardised, it will be easier to prepare uniform visualisation methods for them, just as it will be possible to use them to establish or construct other models for computational or other purposes, not limited to participation.

documents, as well as their feedback potential. The transfer of information about an area to the actual implementation of a proposal is thereby facilitated, moving from non-binding studies to binding plans, together with higher interest from the public about how “their own” input would be later utilised, or, even better, as a compelling argument for initiating the acquisition of such documentation that allows its utilisation, as seen in figure 31 on page 103. Of course, as previously explained, the appropriate visualisation method depends on the scale and phase of the project, as is further demonstrated in figure 32 on page 109.

Additionally, to make sure the Czech planning process is easily understandable for the readers, figure 30 offers a brief diagram of the process, with individual recommendations shown at the supposed step of the process. Also, the phases of the process where the public is involved are highlighted in the diagram.

Given the breadth of this topic, the author acknowledges that certain assertions and findings require more extensive investigation in subsequent research.

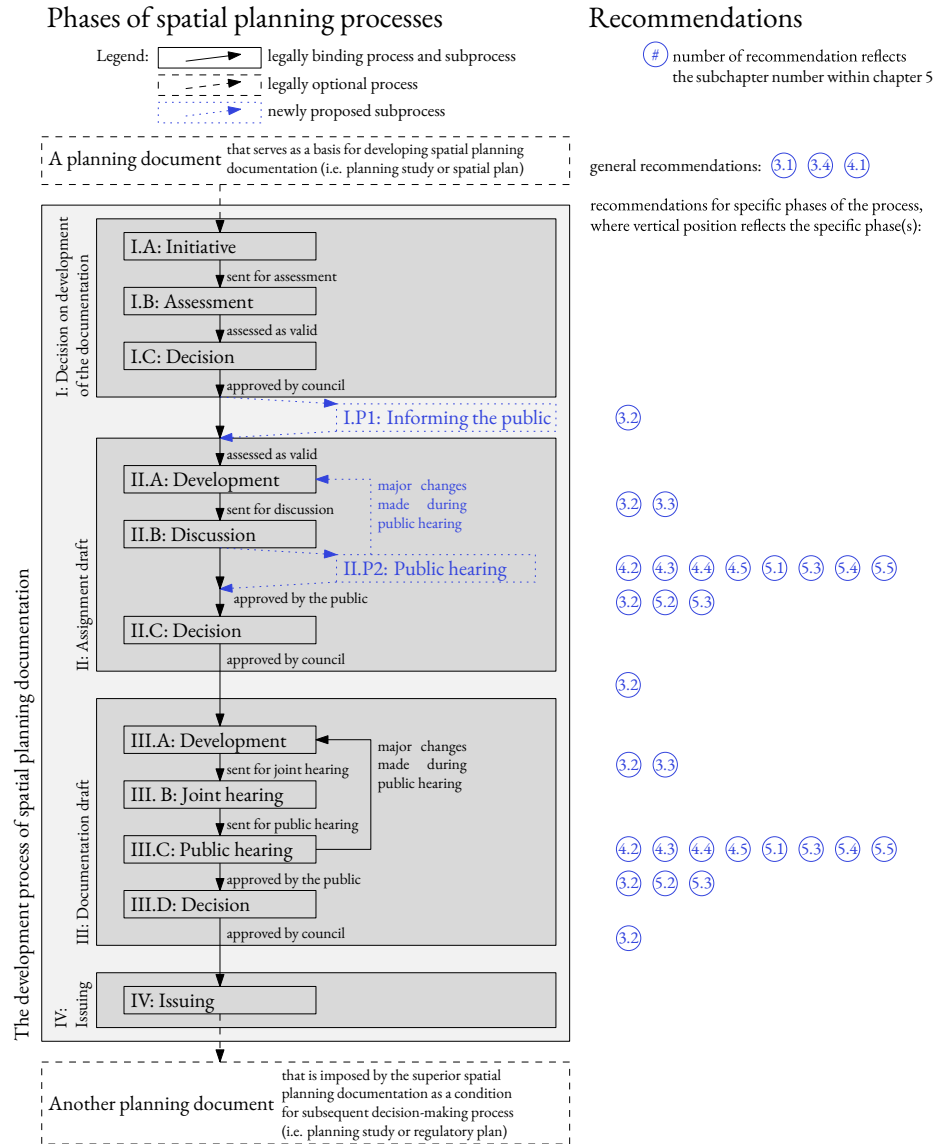


Figure 30: Process of developing spatial planning documentation in Czechia with specific recommendations

5.1 Mitigating participation paradox

Having established the challenges of the participation paradox, which is presented in figure 6 on page 32, it is now explored how XR visualisation methods could help to alleviate this paradox in spatial planning. This recommendation argues that integrating advanced, accessible visualisation tools more often throughout the stages of the planning process, can help citizens to not only understand proposed plans better but also to actively and effectively shape them with feedback from the earliest stages. By early and continuous engagement, XR technologies can simultaneously enhance public knowledge and their capacity to influence outcomes, effectively moving the discourse towards resolving the paradox.

Figure 31 demonstrates the potential of XR visualisation methods in spatial planning. These tools allow for the intuitive and spatially accurate presentation of proposed projects, thereby increasing participant immersion and enhancing their understanding. The utility of XR could be harnessed at every stage of the planning process, from the creation of non-binding analytical documents and binding spatial planning documents to the final realisation of a specific project.

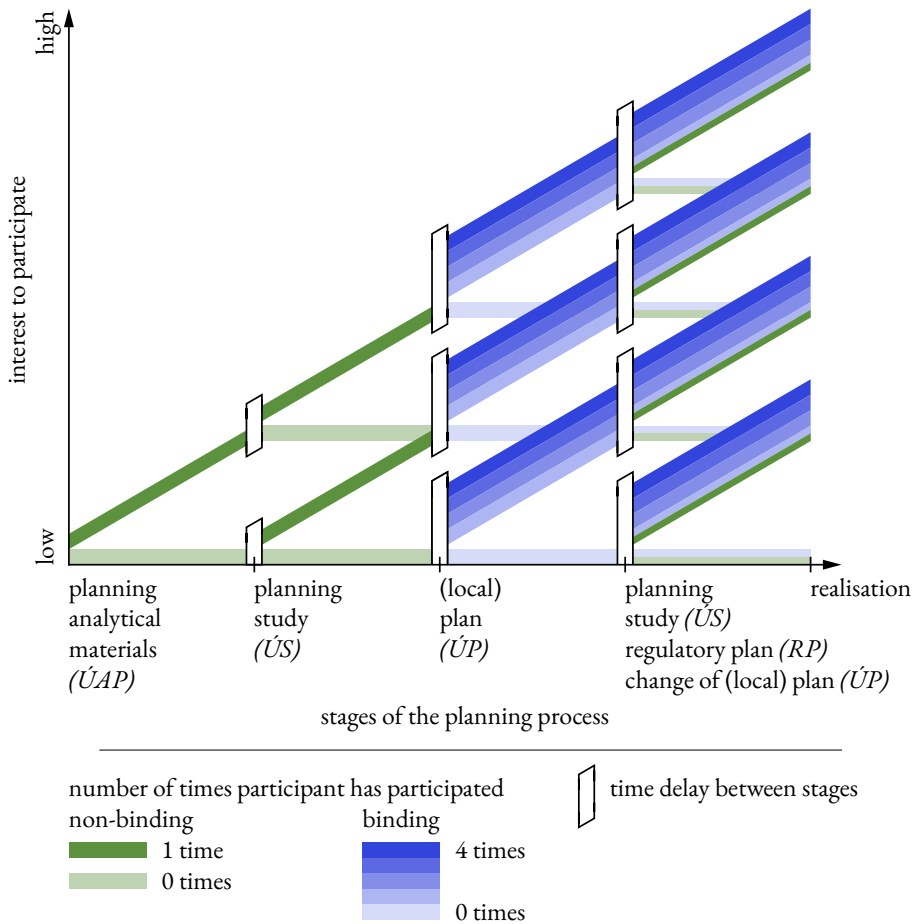


Figure 31: Increasing the interest to participate in subsequent stages of the planning process via XR visualisation methods; this figure is a modification of *Beteiligungsparadoxon* (Reinert & Sinnig, 1997) as seen in figure 6 on page 32, extending its scope from a single, specific planning case (single stage), to illustrating the succession of multiple planning documents (multiple stages), demonstrating intertemporal flow and showing how enhanced engagement in the earliest planning stages (e.g. non-binding studies) has the potential to both grow initial public interest and foster sustained involvement in subsequent, legally binding stages

The early participation is fundamental. Individuals who engage in the initial stages have a greater opportunity to influence the outcome than those who join later (shown higher on the y-axis “interest to participate” in figure 31). Even passive participation, such as observing outputs from previous stages, improves an individual’s information and understanding.

This early interest has the potential to mitigate the participation paradox, where the capacity to influence outcomes decreases over time, while public knowledge generally increases. Figure 31 visualises this paradox across a chain of successive planning tools: the earlier participants engage in the process, the more their knowledge and influence accumulate. XR plays a vital role here by providing accessible and interactive visualisations that enable citizens to better comprehend the spatial implications of proposed solutions and contribute more effectively to the discussion.

If the recommendations brought forth in this chapter were successfully implemented, the legal structure would consequently stipulate more frequent opportunities for public participation throughout the planning process. In binding documents, these would include drafting (1st opportunity), joint negotiations (2nd opportunity), public hearings (3rd opportunity), and after issuance, learning about the outcomes (4th opportunity). The extent of participation in non-binding documents depends on the specific approach of the procurer and designer. This is depicted in figure 31 either as 0, that the option did not exist for the participants, and as 1, where the process did include participation.

For the aforementioned reasons, this recommendation proposes strengthening participation by introducing an additional consultation with stakeholders during the acquisition phase of a given spatial planning instrument. This would broaden the range of participants and help confirm that feedback is incorporated early, while the proposal can still be modified.

Figure 31 depicts two extreme scenarios: minimum participation (represented by lighter shades of colour), where the individual participates passively or not at all, and maximum participation (darker shades), where the individual is involved and has tangible influence from the beginning to the final approval of the solution. The aim of this recommendation is to increase this involvement and influence by leveraging XR technologies to facilitate understanding and engagement throughout the planning process.

5.2 Integrating XR into Czech planning practice

This chapter examines how XR can be integrated into the development process of different spatial planning documents in Czech planning practice. The following figure 32 recommends specific visualisation methods to be employed during development of non-binding planning materials and it also recommends methods for the subprocesses of developing binding spatial planning documentation as defined in figure 30 on page 101, where two new subprocesses are introduced into current planning practice. These subprocesses are designed to enhance the interest to participate, which can further improve the “interest to participate” as shown on the y-axis in figure 31.

5.2.1 Informing the public

The first of the two new subprocesses, i.e. the proposed “I.P1: Informing the public” subprocess, is designed to commence immediately following the decision of the council to approve documentation development. Its primary objective is to proactively inform the public about the newly initiated planning process, to generate interest, and to introduce various methods for future participation in this process. The information about the new process would be distributed early and in more ways than just the legally required notice boards and official records of the council meetings (as these are often overlooked by the public). An effective way to achieve this could be through a mobile application allowing users to subscribe to alerts based on location, making them aware of the planning activities in their vicinity. Such app could be enhanced with AR technologies, so that citizens can learn about the proposed development right away and *in situ*, encouraging dialogue and feedback from the outset to subsequent planning stages.

At this early phase, the planner who would design the planning documentation has not yet been determined. Currently, in the context of Czech legislation, the designated municipal representative (i.e. local politician) collaborates with the planning authority responsible for the area. If the designated representative wishes to involve the public and other stakeholders in the process of formulating the assignment that will later be approved, they may use the previously mentioned materials to present them within an XR environment. Within, participants can explore the underlying information.

Specifically, the information provided in this early phase of the process should include at least the available minimum of background data, such as issues identified in the non-binding planning materials (*ÚPP*), superior spatial planning documentation (*ÚPD*), or other strategic documents. Also, information about a new change of (local) plan (*ÚP*) could include the initiative behind the decision on changing the plan and the current implementation status of the existing plan. The success of this proactive approach therefore can be found by offering citizens a deeper understanding of the planning documentation through leveraging immersive XR visualisation and providing them with this interactive form of providing feedback. The designated representative, acting on behalf of the local community, could then incorporate this feedback into the final assignment proposal. Collaboration between the designated representative or planning authority and an externally contracted party (e.g. a company or facilitator who guides participants through the XR environment and collects feedback) is possible, though not mandatory.

5.2.2 Public hearing

The second of the two new subprocesses, is the “II.P2: Public hearing” subprocess²⁵. This additional hearing could empower the public to influence the assignment of the planning documentation before it is finalised and approved by the council. This recommendation does not replace the legally

²⁵ This newly proposed subprocess “II.P2: Public hearing” is similar to the already existing “III.C: Public hearing” subprocess, but it is positioned earlier in the development of the spatial planning documentation when the assignment is being discussed.

required public hearing in the IIIrd phase, but rather establishes a two-tiered consultation process. The earlier hearing helps confirm that public needs are incorporated already into the assignment of the documentation, while the later hearing still addresses the finalised documentation draft, helping to secure that the assignment is not approved without consideration of these contributions, which could otherwise have long-term consequences in later phases. This dual approach might increase the potential of public acceptance and transparency by facilitating continuous feedback throughout the planning process.

During this process, emerging ideas and spatial principles can be presented using XR technologies, allowing participants to explore spatial overlaps, conceptual schemes, and sketches directly over the planned area. Relevant information from non-binding documents such as issues identified in the planning analytical materials (*ÚAP*) or earlier planning studies (*ÚS*) can also be integrated, providing a more comprehensive and visually grounded setup for discussion and refinement of the assignment.

Specifically, a citizen would be able to view and respond to an overlay of key data, including e.g. areas affected by planning limits, existing spatial values, proposed development intentions and identified spatial problems. Such response could be collected early enough to be incorporated into the assignment draft, due to the feedback loop of the planning process, thereby conserving resources that would otherwise be expended while working on an incomplete assignment.

5.2.3 Recommended usage of visualisation methods

Figure 32 shows the recommended usage of specific visualisation methods within the phases of the Czech planning process, following a common extent of the areas addressed by the respective planning documents and examples from abroad, e.g. Höftberger et al. (2023) or Othengrafen et al. (2023).

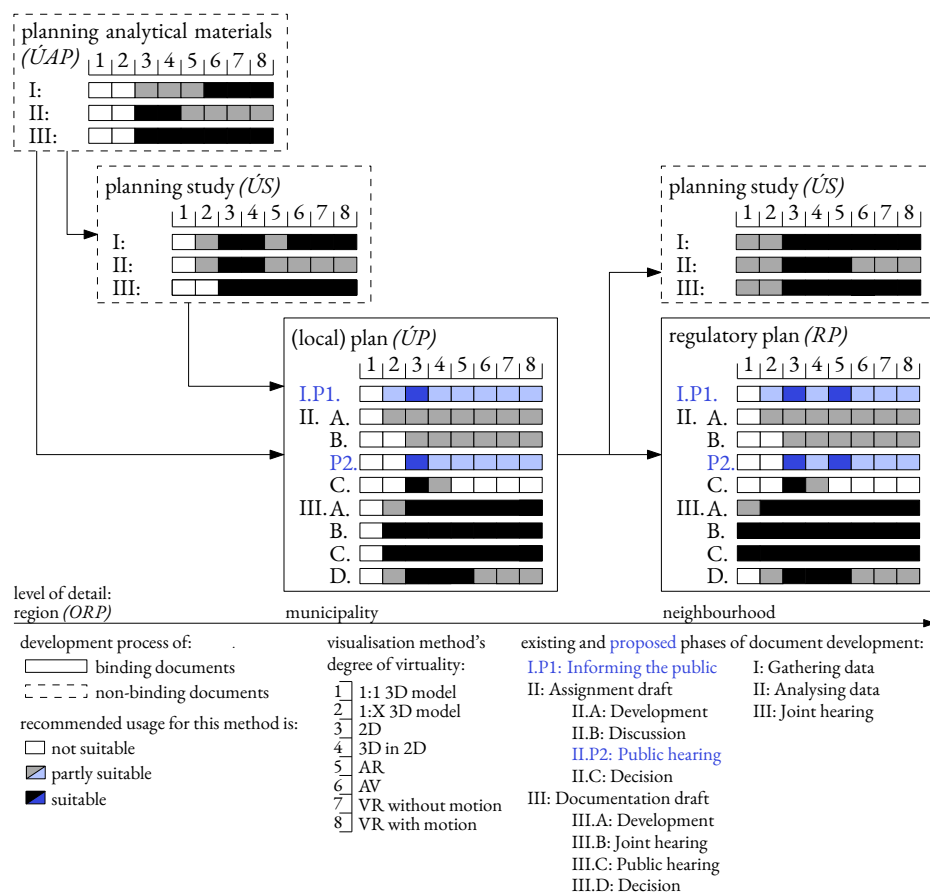


Figure 32: Recommended usage of visualisation methods in the development process of spatial planning documents; coding of the phases of the process for the binding documents remains the same as in figure 30 on page 101

Regarding the non-binding documents, some visualisation methods can enhance user immersion in the planning analytical materials (*ÚAP*), however, they are not applicable for physical 3D models, due to the large extent of the addressed area. For methods 2D, 3D in 2D and AR, only selected aspects can be visualised, however the capabilities of AV and VR allow for a better presentation. These capabilities are still limited by the extent of the area addressed: the greatest number of specific data elements can be visualised at the smallest extent. Larger extents, such as regional or national, can also be visualised; however, the number of data elements that can be effectively displayed is limited due to their broader scale, effectively rendering methods physical 3D models and AR as generally unsuitable for larger extents. On the contrary, 2D method is often considered suitable in all extents, because it reflects current established practice and is therefore commonly adopted.

Other type of the non-binding documents are the planning studies (*ÚS*), which are mentioned twice in figure 32. The two planning studies are included because the first often covers a larger extent (e.g. a planning study for a municipality with extended powers²⁶, *ORP*, as in *obec s rozšířenou působností*), while the second represents a planning study of a smaller extent (e.g. a planning study required by the (local) plan (*ÚP*) as a prerequisite for development in a specific area within a municipality). This distinction allows recommending the appropriate visualisation method based on the scale of the planning study.

²⁶ Such planning studies for larger extent often concern with landscape (e.g. *ÚS krajiny SO ORP Beroun*) or public space (e.g. *ÚS veřejných prostranství v ORP Nová Paka*).

For planning studies (*ÚS*), all visualisation methods can be used in the Ist phase²⁷, with some being partly and others fully suitable. In the IInd phase, the difference between planning studies covering larger and smaller extent is significant: the smaller scale planning study is based on existing regulatory conditions defined by the (local) plan (*ÚP*), and its limited area sometimes allows it to be translated into a 1:1 3D model, e.g. a prototype house type for future use.

Additionally, AR method is not used for the large scale planning study because it would demand visiting an unfeasibly large or abstract territory. Conversely, in the IIIrd phase of the smaller scale planning study, visualisation using a 1:X 3D model is appropriate due to the smaller area, allowing for meaningful consultation over a model.

Regarding the binding documents, in the early assignment draft phases (i.e. the IInd phase), although few outputs have a graphical form, visualisation methods are recommended to allow the designated representative (i.e. local politician) to translate thoughts and requirements into concrete spatial concepts for the designer (i.e. planner responsible for creating the document), or enabling both of these actors to effectively communicate the preliminary scope and priorities to the public for early feedback. This helps confirm that the assignment draft is spatially feasible, politically grounded, and aligned with community expectations before formal planning begins.

²⁷ Unlike binding documents, where the specific phases of their development are legally defined, non-binding planning studies have no predefined phases. Therefore, phases I to III were defined for the purpose of this dissertation based on a general planning workflow in order to be able to better analyse the suitability of visualisation methods.

For the (local) plan (*ÚP*), methods proposed for phase I.P1 are selected because they are suitable for showing the entire area under consideration while integrating existing baseline data available from the planning analytical materials (*ÚAP*) or other known sources, such as strategic documents etc. Methods are sometimes shown as “partly suitable” for the (local) plan, signifying that their application is not for the entire extent of the areas addressed by the plan (phases II.A and II.B) or that the specific method cannot visualise all available data (phase II.A). In phase II.B, the “partly suitable” recommendation denotes that the application is not for the entire extent, and methods AR, AV and VR are included because they show significant potential. The methods are shown as “partly suitable” in phase II.P2 because a definitive spatial situation of the proposed measures is not yet available.

For the preparation of a regulatory plan (*RP*), the same methods and phases as those used for the (local) plan (*ÚP*) are applicable, with the distinction that in phase III.C, a visualisation using a 1:1 3D model is sometimes possible due to the limited extent of the area being addressed. This parallels the smaller-scale planning study described earlier, but in practice, the model presented in the regulatory plan is binding, whereas the model presented in the planning study may not achieve that final form.

The final step, i.e. phase III.D for the binding documents, involves informing participants about the outcome of the respective process of spatial planning document development. Although participants can no longer influence the result, this step remains important as it facilitates

communication of the outcomes of the whole process, which can inform them about their particular interest (e.g. the construction of their own home or development of their neighbouring area) and can improve their participation in future processes.

Finally, for change of (local) plan (*ÚP*), as well as change of regulatory plan (*RP*), XR methods can be applied in a similar way as when developing a brand new document. The key difference, however, lies in the fact that when changing existing planning documents, their current version is already available. This provides broader opportunities for visualisation. Simply put, there is already a base to build upon and to present, which gives greater potential for communication and understanding from the very beginning of the process. For instance, in the case of changing a regulatory plan²⁸, one major advantage is the ability to recreate the existing conditions of the territory as defined by the current regulations, and then directly visualise the proposed changes within the XR environment²⁹. This makes it much clearer for the public to understand what exactly is being modified and how. This highlights a fundamental difference between preparing a completely new planning document and processing a change to an existing one: in the latter case, existing data and spatial layers can be utilised.

²⁸ Regulatory plans are notably less common than (local) plans (*ÚP*), meaning changes to them are also infrequent. For illustration, in Prague, there is currently only one regulatory plan, which underwent just two changes in years 2022 and 2024.

²⁹ It is appropriate to note a related challenge, namely the existence of (local) plans (*ÚP*) that incorporate regulatory elements detailed to a level resembling that of a regulatory plan (*RP*). While such detailed planning is feasible, it is essential to distinguish these instances, as the degree of regulation can vary significantly.

ULTIMATELY, the efficacy of all described XR methods extends beyond visual presentation; successful participation necessitates an active feedback loop. This involves not only demonstrating the proposed changes but also systematically eliciting and documenting the responses of the participants responses (both conscious and subconscious), which subsequently informs the planning process (as detailed in specific recommendations provided in the following sections of this chapter). For AR, active participation can involve the participant choosing a preferred design variant of the proposed development or the collection of *in situ* cognitive data, such as emotional responses and decision-making analysis as the user moves through the real-world visualisation. Similarly, VR affords active engagement, allowing participants to immerse into prepared scenarios and their conscious and subconscious behaviour could improve planning of emergency or traffic infrastructure within the proposed development. For AV, the participant can provide feedback by answering which variant of the proposed development is preferred, and the facilitator can actively monitor and analyse participant behavioural responses and group dynamics during the session.

Summarised, this chapter proposes generally recommended usage for visualisation methods in Czech spatial planning. Having established this, the following sections will provide specific, actionable recommendations for the practical utilisation of XR, grouped by three distinct themes: informed planning, standardised and fair presentation of the visualisation, and enhanced trust and legitimacy by increasing democratic legitimacy.

5.3 Recommendations for informed planning

This section focuses on lowering the barriers in planning practice by increasing public knowledge, awareness, and accessibility to help confirm that planning processes are truly inclusive and representative of the entire community. Specific recommendations include educating citizens on the process, proactively reaching them with project-specific information, promoting equity through outreach, and using technology to reduce social and cognitive anxiety.

5.3.1 Educate the public about planning processes

Many citizens lack baseline knowledge of spatial planning process, jargon, and constraints. That is why “simply” informing the public is essential. By clearly explaining the planning process, timelines, and opportunities for involvement, authorities can educate citizens to participate meaningfully. This education could clarify their options and the limits of their influence, enabling informed engagement. This recommendation could help in counteracting the “paradox of participation” by supporting citizens in being well-informed and equipped to contribute effectively from the outset. As a result, an informed public is better equipped to transition from consultation to co-creation, thereby strengthening the planning process and enhancing its democratic legitimacy. This progression can be conceptually described as climbing towards higher degrees of citizen power on the ladder of participation by Arnstein (1969), see figure 1 on page 9.

This is also where XR can make a difference. Instead of more abstract means of visualisation (e.g. land-use map, using permeability indexes), citizens can use these tools to experience true scale and feel of a proposed development via digital means. These XR means have the potential to transform public participation in spatial planning process from ordinary maps into more relatable experience for the laypeople. However, this relatability can also improve on the trustworthiness of the visualisation experienced by the participant, either positively or negatively, especially when utilising multisensory immersive methods that can mediate real-world impacts, from disturbing effects of traffic to the calming effect of nature.

5.3.2 Improve public awareness and information access

In order to improve public awareness about their options to influence the development of their surroundings, an AR application could utilise geolocation to proactively notify users that come near a proposed development site³⁰, prompting them to learn about the development in the first place and enabling further participation. This would combine the upside of 1:1 3D model with its genuine representation of *genius loci* due to its location specificity, without the downside of building the model physically *in situ*. In this way, people can experience the project in its authentic spatial context, directly connecting abstract plans to their everyday environment.

³⁰ This may refer not only to concrete projects or regulatory plans, but also to broader spatial intentions such as reserved corridors or other strategic proposals appearing in regional or national spatial plans.

This approach transforms awareness from citizen-initiated inquiry to an active delivery process where information reaches them in real time at the exact location. Unlike more general education described in recommendation 5.3.1, this recommendation focuses on awareness for specific development projects that might be relevant for the targeted public. Following this notion, technologies like AR and VR can offer immersive visualisations allowing citizens to assess impacts on their known environment, aesthetics and induced traffic, fostering relatable and effective participation.

Besides the XR app mentioned in the first paragraph of this recommendation, other multi-channel approaches, including social media, project websites, and public forums, should inform about the specifics of the development project and engagement mechanisms, while also enabling active participation and feedback through these platforms on the proposals being presented (described in detail at the end of chapter 5.2.3). Such multi-channel approaches can help a two-way flow of information with different demographic groups, recognising that not everyone has equal access to or comfort with XR.

Additionally, clear communication of influence boundaries empowers citizens to contribute meaningfully, enhancing the democratic legitimacy of project outcomes through focused, inclusive engagement. If people understand exactly what aspects of a project they can shape, their contributions become more relevant, their expectations more realistic, and their trust in the process more resilient.

5.3.3 Promote representative and equitable planning

Inclusive spatial planning requires representative participation from all demographic groups, including those often marginalised, such as young, elderly, and minority communities. Traditional methods often fail to reach these groups due to barriers related to technical jargon, scheduling conflicts, or physical access. Therefore, proactive outreach, language accessibility, and practical support like transportation and childcare are essential to reduce these barriers.

XR could help finding a solution to these challenges by making complex spatial data universally understandable. A citizen who may not grasp technical documents or jargon could more easily comprehend the impact of a proposed development by seeing it virtually in their neighbourhood, where in a case of AR, context would be provided *in situ*. This tangible representation could be more explanatory than numerical indexes often found in spatial planning documents. Furthermore, ICT in general can help to tailor the form of a visualisation to different user groups. An interactive, game-like experience could be created for children, while a simplified, intuitive model could be understandable to the laypeople. This flexibility moves participation beyond technical expertise, enabling meaningful contributions from everyone, regardless of their background or education. This differentiation acknowledges that a “one-size-fits-all” approach to public engagement is inadequate as different groups process and value information in different ways.

By proactively designing visualisations that are accessible and relatable, planning practitioners could help to keep planning from inadvertently privileging only the most vocal or connected groups. However, the scholarly literature also shows that digitalisation may bring new forms of social exclusion or reinforce existing inequalities; e.g. studies on the “digital divide” highlight how unequal access to devices, skills and connectivity continues to disadvantage marginalised groups (Sanders & Scanlon, 2021). In the context of smart-city or digital-planning initiatives, scholars warn of “adverse digital incorporation”, in which inclusion in a digital system gives advantage to already privileged groups, leaving others behind (Heeks, 2022). Therefore, while XR and other visualisation tools hold promise for participation and transparency, they must be deployed with attention to access, literacy, infrastructure and inclusivity, otherwise the promise of equity may remain unmet. On that account, the implementation of digital tools should be an expansion of participatory tools, not a substitution for existing ones. Provision should be maintained for population segments who remain offline or lack adequate ICT literacy. Consequently, the continued offering of traditional analog and face-to-face channels is helping to assure that all citizens retain an opportunity to engage with the planning process, upholding the universal right to participation. Eventually, proactively designing visualisations that are accessible and relatable can contribute to planning being less likely to inadvertently privilege the views of only the most vocal or connected groups, which in turn helps foster genuinely equitable outcomes.

5.3.4 Reduce participation anxiety

Many citizens, particularly laypeople or minorities, can feel intimidated by formal public meetings and the technical terminology used in spatial planning. This social and cognitive anxiety could act as a significant barrier, preventing diverse voices from being heard. Designing a welcoming planning process should therefore be fundamental to fostering a truly inclusive environment.

XR provides a possible solution by bypassing these traditional barriers using technology. A participant who may not grasp complex planning documents or concepts like FAR can comprehend the impact of a proposed development by seeing it rendered in own neighbourhood. For instance, a single mother working shifts may lack the time or inclination for a formal consultation but can intuitively understand what a new public space will feel like by viewing an AR model on her phone. She can then provide feedback at her convenience, without needing the time or confidence for a public meeting.

Furthermore, digital technologies allow for the customisation of visualisations to suit different users, contributing to an intuitive experience for all groups and ages. This customisation should extend to the feedback mechanism itself: for youth, gamified approaches like builder games or design challenges can be used; for adults, feedback can be concise and detailed; and for anybody with special needs, accessible formats should be provided, e.g. larger text, high contrast, and simple, intuitive navigation. Such flexibility not only removes barriers but actively affirms that all forms of input are valid, helping participants feel their perspective is valued, not marginal.

5.4 Recommendations for fair presentation

This section outlines strategies for creating visualisations that are clear, accurate, and consistent to make a basis for fair and transparent proposals to the public. Specific recommendations focus on making complex data accessible to laypeople, preventing participants from being overwhelmed by detail, contributing to visualisations that reflect realistic conditions, and establishing standards to prevent manipulation.

5.4.1 Visualise complex indicators accessibly

Many spatial planning tools rely on abstract indexes (e.g. density, permeability or solar access) that are inaccessible to laypeople. While useful for experts, these indicators often remain incomprehensible for non-specialists, who may struggle to connect a numerical value with its real-world implications. Consequently, these indicators should be translated into easily understandable visual formats, such as diagrams, infographics, or annotated overlays. For example, instead of presenting a table of density values, a colour-coded map or a 3D massing model could directly show how different densities translate into actual building forms. Interactive XR simulations can further aid comprehension by showing real-time impacts of changing parameters. This means that citizens are not just passive recipients of information but can actively explore “what if” scenarios: adjusting variables like building height, street width, or greenery coverage and immediately seeing the resulting changes.

Another example of difficult interpretation is when a numeric permeability index fails to convey its environmental impact; an effective visualisation could show multiple design variants with different ratios of e.g. a grey car park versus a green, porous surface. This would allow people to intuitively understand how paving choices affect water absorption, heat accumulation, or biodiversity in a developed area with surrounding context. Similarly, an interactive model could show a proposed building at different heights, including its maximum allowable height, alongside neighbouring existing structures, making its fit within the urban fabric immediately clear to viewers. Such comparative representations help avoid the common mismatch between expert jargon and citizens' everyday spatial experience.

Overall, these accessible visualisations should be applied to all forms of legally binding documents³¹ and non-binding materials alike. This helps achieve consistency and helps with preventing a situation where only polished, non-binding documents are understandable, while the binding documents remain opaque³². This practice is relevant across all phases of the process, but is particularly impactful during the initial phases when public input can still have a meaningful effect on the outcome.

³¹ Although all forms of legally binding documents include all levels of administrative division (national, regional, and municipal), the higher levels (national and regional) typically address the topics on a broader scale, which may appear more abstract to the public. In contrast, documentation at the municipal level tends to be more tangible and relatable, as it concerns areas familiar to citizens. Nevertheless, with correct LOD, the same visualisation methods can effectively represent higher level documents as well, and awareness of this higher level enables participants to engage in local level discussions with a deeper understanding of the overarching spatial context (see figure 32 on page 109).

³² The requirement for standardising the content of the visualisations utilised in binding planning documents demands further investigation in future studies.

By demystifying technical criteria, participants could provide more informed input and the process could become more inclusive and educational, empowering community members to engage with planners on a more equal footing. In the long run, this also builds capacity within the community, as people become more knowledgeable about spatial issues and more confident in voicing their perspectives.

5.4.2 Reduce cognitive overload

Planning documents and visualisations often present a large volume of complex information, overwhelming participants. It is therefore essential to manage this cognitive load by applying principles of information design: presenting the most important data first and employing visual hierarchy to guide attention. In other words, participants should be able to quickly grasp the “big picture” before diving into details, much like reading a newspaper where headlines, subheadings and text are structured for clarity.

In Czechia, legally binding documents are often functionally inaccessible to laypeople due to their technical jargon and format. Even motivated citizens may struggle to navigate these materials, which are written primarily for legal compliance, not public understanding. This creates a significant information asymmetry and power imbalance, so planners should curate visualisations to avoid manipulation and overwhelming the public with every detail. Here, curating does not mean filtering out inconvenient facts, but easier structuring information so that people can make sense of it without specialised training.

For instance, a visualisation that is too detailed, e.g. showing a proposed building with fully grown trees and vibrant street, can obscure its true dimensions or it can ignore the early years when vegetation is not yet fully grown or the time of the day when the area would be empty and depopulated. Such “beautified” imagery risks creating unrealistic expectations or, conversely, hiding potential problems, which can undermine trust once the built reality diverges from the polished visual. A more transparent approach uses a simple model to isolate the dimensions of the proposed development, helping to keep participants focused on the core design. Additional layers of information (such as greenery growth stages or seasonal use of public space) can then be added progressively, but always in a way that makes clear distinctions between current state, projections, and long-term visions. This can move the planning process towards being more collaborative, supporting that public input substantively contributes to the final plan.

Simplifying visualisations enables meaningful engagement by aligning information presentation with human cognitive limits. Rather than assuming that “more detail equals more transparency”, planners must recognise that clarity and accessibility are prerequisites for genuine participation. This empowerment is a necessary condition to provide all citizens with equal footing to participate fully, leading to more resilient and widely accepted spatial planning outcomes. Ultimately, when everyone can understand and question the proposals, decisions gain democratic legitimacy and longer-term societal support.

5.4.3 Uphold realistic and contextual representation

Visualisations should accurately represent real-world conditions to avoid misleading the public. While photorealistic renderings are powerful, they can create false expectations if they omit contextual elements such as traffic, infrastructure limitations or construction impacts. It should be essential to visualise dynamic, often intangible, aspects of a project. These include not only physical structures, but also temporal changes, sensory qualities, and the social dynamics that shape how a place will actually be experienced.

Using immersive XR visualisations, it would be possible to include simulated sensory experiences when presenting proposed development. For example, a planner could model the expected traffic noise or air pollution levels from a new motorway, allowing citizens to hear and feel the impact of when it will be finished. Such multisensory simulations can bridge the gap between abstract data (like decibel levels or particulate matter pollution) and lived human perception, which is necessary for inclusive decision-making. Similarly, a visualisation could simulate the stress and noise from a construction site during different phases of development, providing a tangible experience of the whole project lifecycle. This holistic approach provides that citizens are not only exposed to the final, polished state of development but also to the transitional phases that directly affect their daily lives.

Highly detailed visualisations, while capable of fostering deeper understanding, they also carry the potential for manipulation. The intentional creation of an idealised or sanitised experience could be used to mislead

public opinion and stifle opposition. This concern is exacerbated by future technologies, such as neural links, which increase the realism of the representation and thus the creator's ability to manipulate, as discussed in chapters 4.4 and 4.7. As immersion deepens, the ethical responsibility of planners and designers to disclose what is simulated, estimated, or uncertain becomes more critical.

Effective visualisation should be carefully balanced and fully transparent to avoid manipulation. Grounding designs in realistic representation can help participants make better, more informed judgments, which contributes to the credibility of the planning process. Ultimately, visualisations should be seen not as marketing tools but as democratic instruments, designed to inform, not persuade, which is the foundation for legitimate and resilient planning outcomes.

5.4.4 Standardise the visualisations

A lack of standardised guidelines can lead to disparate visual styles that have increased probability to confuse participants and create significant disparities in how information is interpreted across projects, therefore standardisation should be adopted for 3D models, colour schemes, legend usage, and data overlays. Without clear standards, each visualisation may appear in a completely different format (sometimes as photorealistic renderings, other times as rough sketches) which makes comparison unfair and leaves room for selective interpretations.

Standardisation also enhances accessibility and fosters equity. When participants are familiar with a unified visual language, they can more easily interpret details of a new project, enabling more accurate analysis and feedback. In practice, this means that once citizens learn to read one set of symbols and colours, they can transfer this knowledge to other projects, becoming more confident and effective participants in the planning process. The responsibility for maintaining these standards should fall to the planning authority or the mediator who fosters the development of the planning documents. These mediators should ensure that all visual outputs, regardless of the software or maker, adhere to a single, coherent style. A significant focus of this scrutiny should be preventing any manipulation through visual means, such as the use of overly idealised renderings that could bias public perception.

Another important aspect of this standardisation is the consistent application of legends, symbols and function definitions on all virtual 3D models. This application should clearly explain the use of different elements, such as distinguishing between different combinations of density of residential, commercial, industrial or public spaces. By standardising these visual elements, it could prove easier to help citizens to understand and evaluate spatial planning proposals with confidence.

5.4.5 Prevent aesthetic manipulation

Visualisations in spatial planning should be an accurate representation of proposals, not a form of persuasion. Highly polished visualisations that

rely on aesthetic enhancements (e.g. unrealistic lighting, flawless blue skies, lush greenery, or attractive, idealised people) can bias public perception and distract from the substantive issues or demerits of a project. Inner workings of such visualisations often operate on an emotional level, triggering positive associations that overshadow critical evaluation of scale, functionality, or environmental impact. Resulting bias can be a form of manipulation that undermines trust and discourages engagement with the planning proposal. Crucially, when employing XR, this risk of manipulation is amplified: the inherent depth of immersion makes these extended visualisation methods (as presented in chapter 4.2) more susceptible to manipulative aesthetics than traditional methods (as presented in chapter 4.1), potentially affecting participants in ways they cannot fully discern. Immersive technologies do not only show images but create experiences, and when those experiences are artificially beautified, the boundary between representation and persuasion becomes blurred.

This could be countered by ethical guidelines for visuals. To promote impartiality and consistency, visualisations would be created by a single entity (e.g. the planning authority or independent companies) or that entity could audit and verify produced visuals meet established criteria (e.g. a predetermined vantage point). This standardisation would help confirm an impartial visual baseline across realistic scenarios including varying weather conditions and times of day, providing honest and holistic view of the potential development.

The ethical use of aesthetics is a matter of professional responsibility. In this sense, visualisations should be treated with the same ethical seriousness as statistical data: selective presentation can distort reality just as much as manipulated numbers. It requires impartiality and visualisations adhering to an established code, prioritising clarity and honesty over marketing. A planning process as such could promote critical engagement and builds public confidence.

5.5 Recommendations for democratic legitimacy

This section focuses on recommendations and requirements to support the goal that public engagement is meaningful, transparent, and genuinely influential, thereby building public trust and validating the planning outcomes. Specific recommendations call for authorities committing to constructive feedback, establishing auditable documentation loops, constructively managing disagreements, and working towards guaranteeing participation is timed to maximise influence.

5.5.1 Empower public influence on decisions

Participants must have the ability to genuinely influence the planning outcomes, rather than simply being included as a formality. In practice, this means that their voices must have a real impact on final decisions, not just be acknowledged in reports without consequences. This requires increased demands for implementing public input, facilitating that feedback leads to

actionable decisions. In other words, suggestions should not end up in a “black box” of consultation, but must be clearly traceable in how they shape the outcome. Institutions should establish transparent criteria for how suggestions are evaluated and integrated, preventing the perception that public involvement is merely symbolic.

The empowerment of participants in this context is linked to the application of XR technologies: it facilitates this objective through two principal mechanisms. Firstly, by providing immersive, human-scaled visualisations, these tools can help with public understanding of complex planning proposals, enabling participants to provide more informed and relevant feedback. Instead of interpreting abstract technical drawings or statistical data, citizens can “walk through” proposed spaces virtually, which reduces misunderstandings and supports constructive dialogue. This deepened comprehension favours that contributions are based on a holistic understanding of the project, not on misinterpretations. Secondly, XR enables participatory planning at a significantly earlier phase in the process. By visualising data in suitable format³³, these technologies make potential issues and opportunities transparent before a project’s details are decided and fixed. For instance, heat maps of social exclusion or 3D models of environmental risks can be displayed alongside concrete design options, making abstract concerns tangible. This pre-emptive access to information empowers citizens

³³ As recommended in figure 32 on page 109, while considering applicable visualisation methods due to different characters of data (i.e. abstract character, such as index of social exclusion, or concrete character, such as location of brownfields), scale and phase of the project.

to voice their feedback (and contribute their own data) at the earlier phases of the decision-making cycle, when the active participation and feedback capture enabled by these technologies has the largest potential to impact the decision making. The method of feedback collection is contingent upon the specific XR method employed, e.g. choice of preferred design in AR or analysis of orientation and emotional responses in VR, as described in more detail at the end of chapter 5.2.3.

These XR methods are intended as an extension to existing participatory planning; they do not prohibit citizens from submitting comments via traditional means, such as digitally completed forms sent by email or manually written statements. The captured feedback is directed to the facilitator, who utilises the structured data to the refinement of the design proposal, thereby ensuring the subsequent response of the public is grounded and documented. This systematic collection and utilisation of early feedback is essential, as it targets the phase, when the active participation and feedback capture enabled by these technologies has the largest potential to impact the decision making. At this point, adjustments are still feasible without significant financial or political costs, which increases the willingness of institutions to adopt public input³⁴. Such proactive approach cultivates public trust and enhances the legitimacy of the process. When people can clearly see how their contributions have influenced outcomes, they develop a stronger sense of ownership and confidence in the fairness of planning decisions.

³⁴ This dissertation proposes new phases of the planning process, where such public input can be gathered, which, in turn, increases the opportunity for dialogue.

5.5.2 Reinforce validity of the planning process

To counter public scepticism, planning processes must be visibly fair and open and the feedback from participants should be noted. It is not enough to merely register that input was received: what matters is a transparent mechanism showing how contributions are tracked, evaluated, and either incorporated into the final design or excluded with clear justification. Therefore, a fundamental requirement is the establishment of a robust feedback loop where citizen contributions are not only acknowledged but also systematically documented. Such documentation would serve as an institutional record, providing an auditable trail from public input to final decisions, thereby fostering trust.

In this regard, XR technologies enable deeper, more nuanced feedback. During an immersive visualisation, emotional and experiential responses of the participant can be documented in real-time. Instead of relying only on written comments, planners can observe how people react while engaging with a proposed development, capturing data that would otherwise remain hidden. For example, combining XR with eye-tracking during a virtual walkthrough of a proposed public space can reveal where participants focus. This information can be used for safer designs, such as optimised emergency escape routes or pedestrian areas safer from traffic. These records could also capture emotional and experiential responses, transforming subjective input into actionable data. This transforms “soft” impressions, like a feeling of crowding or discomfort, into structured evidence that can directly inform spatial choices.

By retrieving and integrating previously documented feedback into design revisions, planners could demonstrate how public input shapes outcomes, closing the feedback loop and reinforcing the legitimacy of planning processes, when the participants can see their feedback truly realised, which might, in turn, increase their interest to participate and, consequently, help alleviating the participation paradox. The participation paradox, where those most affected by planning often engage the least, can be gradually addressed if citizens see tangible proof that their voices matter, motivating broader and more diverse involvement in future projects.

5.5.3 Address and document constructive disagreements

Constructive disagreement is a sign of healthy engagement. And ignoring or suppressing dissenting views can undermine the legitimacy of any agreement. Therefore, the planning process must provide dedicated space for conflicts, equipped with robust mechanisms for both documenting and responding to them constructively.

XR could help in capturing and managing such conflicts. Beyond traditional verbal or written feedback, XR allows for the documentation of direct, experiential reactions to a proposal. For instance, gestures, comments or suggestions of the participant are recorded during an AR or VR walk-through of an overly dense development design. These qualitative insights could become data points that capture the core of a disagreement in a way that a simple survey cannot.

Similarly as in recommendation 5.5.2, by systematically documenting these nuanced reactions, whether through video, audio or other data, an auditable record of the issue is created. This historical record can then be retrieved during later project phases to demonstrate how specific dissenting feedback was considered and addressed in subsequent design iterations. This transparent process of channelling conflict into a constructive record is essential for managing expectations and building public trust. Structured debates and mediated dialogues, informed by these concrete data points, can transform disagreement from an obstacle into more robust, well-considered, and publicly legitimate planning outcomes.

5.5.4 Avoid participation with predetermined outcomes

For planning processes to obtain true legitimacy, the outputs of these processes must be open to change. If key decisions are already made, public input becomes little more than a *façade*, undermining the entire purpose of engagement. Therefore, planning authorities, practitioners and developers should commit to a mindset of co-creating with the public. This commitment requires an institutional willingness to integrate feedback and revise plans and other planning outputs where warranted. Such case would demonstrate that public contributions are not just heard but acted upon and improved consensus could reduce legal disputes and leading to faster project acceptance. In practice, early revisions based on feedback can save time and resources by preventing costly appeals, protests, or litigation at later phases.

XR can prove as tool that can help in this commitment in a way that immersive visualisations can provide an iterative process where successive versions of a design are presented to the participants, showing how previous public feedback has been integrated. For example, a side-by-side comparison of an original proposal and a revised version, with specific design changes highlighted and linked to public input, offers evidence that the process is authentic. This clear, visual documentation could demonstrate authenticity and build public trust.

The ability to visually trace the evolution of a project in response to public input helps to show actual results of participatory planning. Discerning a “before and after” empowers citizens to recognise their role in shaping outcomes, reinforcing the sense that engagement is worthwhile. By systematically showcasing how contributions led to tangible changes, more authentic and robust planning outcome can be achieved in the long run.

5.5.5 Straighten the temporal dynamics

Participation should occur when it can still influence outcomes. Public input should be aligned with main decision points, to be able to react with feedback. Moreover, sufficient time should be allowed for the participants for learning, discussion, and responses. Rushed participation undermines quality and weakens legitimacy. If citizens are invited to comment only after core decisions have been fixed, their participation serves merely as a symbolic gesture, often leading to dissatisfaction and distrust in the process.

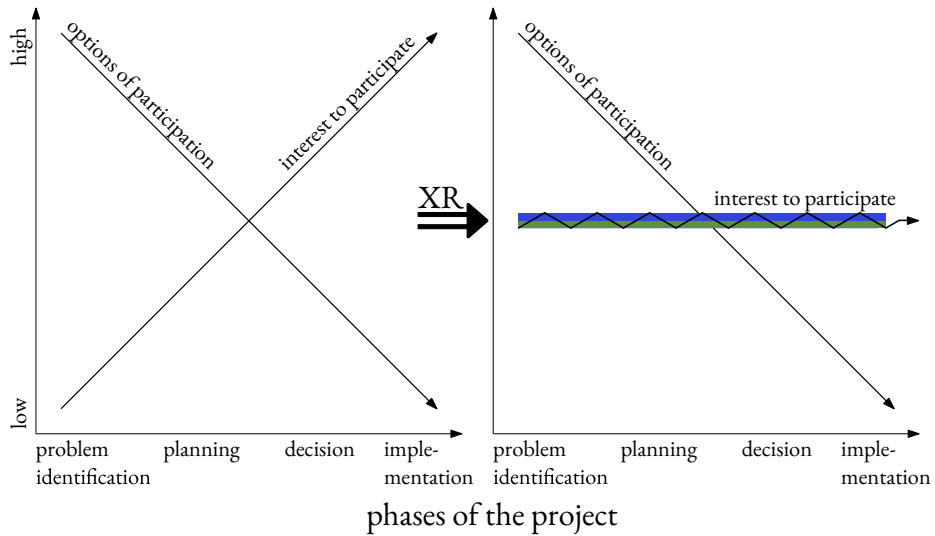


Figure 33: Desired alleviation of the participation paradox; left half is adopted from Reinert and Sinnig (1997), while the right half shows how the paradox could be alleviated using XR: this is expressed by the blue and green line representing the binding and non-binding documents, where the public is invited to participate more often and earlier in the process, increasing their influence on the outcome while also increasing their interest in the project

In this way, the aforementioned participation paradox (as presented in figure 6 on page 32) could be avoided.

Also, it is customary to note that the preceding recommendations were also shaped to alleviate this participation paradox.

OVERALL, these recommendations aim for more ethical and effective planning. The next chapter builds on these ideas by combining the recommendations from this chapter with lessons learned in tackling the participation paradox (see figure 31 on page 103) and with an analysis of how XR is used in specific phases of spatial planning (see figure 32 on page 109).

6

Discussion

APPPLICATION of ICT in spatial planning can improve the results of spatial planning processes, increase their transparency, broaden access to information for the public, and facilitate earlier, evidence-based engagement. Additionally, spatial planning practice in the earliest and most formative stages is repeatedly undermined by the so-called “paradox of participation”: when influence is greatest, interest in participating is lowest; when interest peaks, options for change are already constrained (Reinert & Sinnig, 1997). XR and especially MR visualisation methods offer a possible remedy, since they reduce the abstraction of early proposals and allow laypeople to experience spatial change before it becomes fixed in drawings or contracts (Wolf et al., 2020). Literature reviews demonstrate that XR can enhance comprehensibility, interactivity, and traceability of proposals: three properties that can shift engagement into earlier stages, while also stressing that the benefits depend on context-sensitive implementation and on guidelines for accessibility and ethical use. XR should complement, not replace, established participatory instruments, and its use should be integrated into formats and places where citizens are already present.

Empirical work on 3D geovisualisations clarifies why “more realism” does not automatically guarantee better participation (Hunter et al., 2022). In an experimental study, Jaalama et al. (2021) show that perception is shaped by the interaction between sense of presence (the degree to which the medium conveys the scene) and sense of place (the meanings and opportunities people attach to it). Prior familiarity with the area systematically influenced both

perceptions and preferred outcomes: respondents who knew the site tended to favour its preservation. Photorealistic 3D models therefore have most value as supportive tools (secondary to actual site visits) and illustrate that visualisations are seldom neutral, but carry interpretive frames.

These findings point to important implications for participatory design. Immersion should be accompanied by cues that highlight opportunities and constraints (e.g. routes, thresholds, or microclimatic exposures) rather than relying on photorealism alone. Participatory tools must also account for user heterogeneity: differences in digital skills and personal experience shape how people interpret and evaluate visualisations, even when the interface itself is perceived as intuitive. A single, expert-grade model or narrative is therefore unlikely to serve all publics equally without additional scaffolding and multiple, parallel ways of exploring a proposal (Wolf et al., 2020).

MR can also be understood as a learning medium, offering a “toolbox” of features (e.g. freedom of design, adaptivity, reproducibility, and presence) that can be orchestrated to support transparent comparison of alternatives and to document how participants engage with them. Used strategically, in accessible venues and guided by clear questions, these features lower barriers to participation and facilitate dialogue across stakeholder groups. Conversely, unspecific or poorly targeted deployments risk discouraging participants or reintroducing opacity under a high-tech *façade*.

Applied AR systems demonstrate how these principles can be implemented in workshops. Tomkins and Lange (2019) present a modular AR

workflow that generates terrain visualisations from digital elevation models, simulates flood progression, and allows multiple users to intervene in real time. By offering both marker-based tracking (shared perspective) and environmental tracking (on-site or distributed use), the tool can support different phases of a process: orienting participants to a site, interrogating risks, and co-designing interventions that can be immediately tested and exported for further analysis. Compared with touch-tables or paper maps, AR supports both personal and shared views simultaneously and accommodates larger groups without forcing all users into a single perspective.

Sustained motivation is not an automatic by-product of immersion but a result of careful process design. Evidence from the “Game.UP” project (Muehlhaus et al., 2023) shows that specific gameful elements can reinforce motivational dimensions such as perceived autonomy, competence, and social relatedness, while poorly chosen elements may add unnecessary complexity. Gamification should therefore not be understood as a universal set of points, badges, and leaderboards, but as a context-sensitive reframing of interaction that, when aligned with stakeholder needs, reshapes the very way in which citizens relate to participation.

While these examples demonstrate the potential of XR and related approaches to reduce abstraction, foster earlier engagement, and support more collaborative forms of design, they also underscore the centrality of interpretation and accessibility. The effectiveness of visualisation does not depend solely on technical capacity, but on whether participants are able to

meaningfully relate visual inputs to their own lived environment and to wider planning goals. Public participation in spatial planning therefore hinges not only on formal rules and participatory methods, but above all on the ability of citizens to understand the spatial reality of proposed development.

The general public often struggles with interpreting conventional planning outputs such as maps, regulatory drawings, or spatial coefficients. This level of abstraction can represent a significant barrier to the genuine involvement of residents in shaping the environments in which they live. XR technologies offer a means of overcoming this barrier: when used appropriately, they can make proposed development accessible even to non-experts through human-scale visualisations (Martín-Gutiérrez et al., 2017; Meenar & Kitson, 2020). This not only enhances the legitimacy of planning decisions but also encourages meaningful and timely public participation that occurs before decisions are effectively finalised (Vassiljev et al., 2020).

In practice, the use of XR tools in contemporary planning is uneven, and spatial visualisation may paradoxically serve to reinforce technocratic or purely investor-driven interests. Studies focusing on suburban settlements indicate that the absence of transitional zones between built-up areas and open landscapes (Glenny et al., 2023; Mañas & Kabrhel, 2024b; Mañas et al., 2023; Titzenthalerová, 2012), the increase in impermeable surfaces, and spatial fragmentation lead to the degradation of both environmental and social functions at the urban periphery. When these phenomena are

visualised in a one-sided manner (e.g. as “new housing with views of the countryside” without representing the impacts on ecosystems, accessibility, or microclimate), they may function more as a visually appealing yet potentially misleading communication tool than a basis for informed decision-making.

Furthermore, the loss of traditional ecotones between settlements and the surrounding landscape, combined with the proliferation of isolated and impermeable enclaves, leads not only to ecological damage but also to the social detachment of new neighbourhoods from their broader urban and rural context (Mañas & Kabrhel, 2024a, 2024c). In such cases, XR offer significant potential as platforms for spatial intervention, allowing for the simulation of alternative scenarios (green corridors, path networks or permeability solutions (Othengrafen et al., 2023) etc.) prior to implementation (Allen et al., 2011; Pan & Zhang, 2021). Data on permeability, ecological value, or recreational potential can be integrated into XR models to illustrate different development options in an accessible and spatially anchored form (Cheng & Shen, 2019). XR could thus support proactive optimisation of proposals, with the active involvement of the public (T.-H. Lin et al., 2015). Yet another advantage of XR is that the public can be invited for a participation event in the case when its time or place is inaccessible to them, for any subjective or objective reason (Ehab & Heath, 2023; Han & Lee, 2023).

However, this also highlights the necessity of accompanying participatory visualisations with clear, unprejudiced interpretation. If participants are exposed to immersive content without adequate contextual understanding,

there is a risk that aesthetic appeal may outweigh functional and ecologically well-founded solutions. Effective participation, therefore, requires not only access to XR tools but also guided interpretation, ideally provided by public sector representatives tasked with defending the public interest. This extends beyond legal compliance: planners or public officials should also act as mediators of thematic content, helping citizens navigate complex spatial information in a meaningful way. Without such educational support, participatory judgement may default to subjective preferences rather than informed deliberation. Consequently, one of the broader objectives of this dissertation is to provide recommendations to help operationalise this educational role and strengthen the basis for informed, public interest-driven decision-making.

Furthermore, findings from recent studies show the important role that the physical and perceived permeability of settlement edges plays in residents' daily lives and in shaping their relationship to the surrounding landscape. Whereas access to open countryside was once a given in traditional rural environments, it has increasingly become a privilege in contemporary peri-urban and suburban contexts (Psotová, 2008; Ryan, 2006). XR technologies offer an opportunity to restore this dimension already at the early stages of planning process by making permeability tangible through simulations of visual connections, access routes, or acoustic environments (McKenzie et al., 2023; Raghuvanshi & Gamper, 2023). Such applications open new pathways for participatory design, in which residents are not only

invited to evaluate proposed alternatives, but also to suggest modifications based on an embodied spatial experience, rather than relying on abstract or interpretive impressions from conventional planning documents (Muehlhaus et al., 2023; Wolf et al., 2020).

IT is important to note that virtual simulations should not be understood as self-serving technological novelties. Research suggests that a higher level of visualisation does not automatically lead to better understanding or more meaningful participation, particularly at the higher levels of engagement as defined in participatory typologies (Abbate et al., 2023; Boos et al., 2023). More critical than the LOI is the way in which XR technologies present information: whether they allow users to explore, reflect critically, and compare alternatives, or whether they create an illusion of complexity that overwhelms users and impedes orientation (Olsson et al., 2012). Overly detailed models that lack a clear information hierarchy (Biljecki et al., 2014) can be just as ineffective as oversimplified representations, e.g. paper plans that are, in the end, more affordable but equally limited. The challenge going forward is to find an optimal balance between visual fidelity, clarity, and cognitive load, ensuring that LODs are used thoughtfully to avoid cognitive overload and to support informed engagement.

This approach raises a question of who is responsible for interpreting the visualisations and determining what information the public actually receives. While XR tools are technically neutral, their effects are never neutral; the outcomes always depend on the data selection, the manner in which the

information is presented, and the context in which it is communicated. If these visualisations are prepared unilaterally, for instance, by a developer or any other party with a vested interest in the area, there is a risk that they will primarily serve as a tool of persuasion rather than (or more than) as an informative resource. Aesthetically appealing proposals, presented without expert commentary (or with bias), are almost always perceived as desirable, regardless of their impacts on climate, mobility, or social cohesion.

For this reason, the interpretation of visualisations should be regarded as an integral part of participation, not merely as an accompanying service. It is not enough for the organiser to fulfil the legal obligation³⁵; they must also actively convey the meaning, explaining thematically what the individual elements represent in relation to the goals and tasks of spatial planning, as well as the themes to which Czechia, as an EU member state, has committed³⁶, such

³⁵ This term typically refers to the statutory requirement to conduct public consultation processes, which are often limited to procedural explanations and references to legal paragraphs that are largely inaccessible to the general public. As a result, participation may become a mere formality rather than a meaningful engagement. It is acknowledged, however, that public administrators are not researchers but civil servants; still, the involvement of a well-informed, impartial representative of the public sector capable of contextual interpretation would be highly desirable.

³⁶ This refers in particular to the obligations derived from the United Nations' Agenda 2030 for Sustainable Development (United Nations, 2015), especially Goal 11.3: "Enhance inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlement planning and management in all countries", Goal 16.7: "Ensure responsive, inclusive, participatory and representative decision-making at all levels" and Goal 16.8: "Broaden and strengthen the participation of developing countries in the institutions of global governance".

as sustainability, resilience, inclusion³⁷, and the support of ecosystem services, among others. This is not solely the responsibility of the designer, who is generally bound by the contract with the municipality, but primarily that of the public sector representative, who should act as an impartial guarantor of the public interest and advocate for the long-term planning horizon. It is their voice that can balance the influence of one-sided visualisations and provide citizens with information on which they can truly assess what is true, rather than merely what is attractive or compelling.

This need for explanation and independent mediator is closely linked to the participants' understanding of and competence within participatory processes. Most people are not equipped to evaluate complex urban or development proposals based solely on visual impressions, and this is especially true in the world of XR, where the realism of a model can easily mask its misleading nature. Therefore, it is essential that participation is not understood merely as the expression of an opinion, but as a process that also includes educating the public. This could take the form of thematic workshops, guided projections or interactive applications that not only display but also explain, e.g. why densification is important for sustainable

³⁷ The term “inclusion” in this context reflects the Principles of urban policy (*ZUP*, as in *Zásady urbánní politiky*), where inclusion (particularly in the context of innovation and digitalisation) is linked to the “stimulation of efficient SMART solutions, enhanced communication between citizens and authorities, and the creation of new opportunities for participation” (Ministerstvo pro místní rozvoj ČR, 2023). It also reflects the priorities of the Spatial development policy (*PÚR*, as in *Politika územního rozvoje*), e.g. priority 16 stating that “Appropriate solutions for spatial development should be sought in cooperation with the inhabitants of the territory and its users...”, and priority 28 stating that planning “...should be addressed through the cooperation of the public and private sectors with the public” (Ministerstvo pro místní rozvoj ČR, 2024b).

transportation, how building height affects the microclimate or how surface types influence rainwater infiltration. Additionally, it could involve exploring how many trees can be planted in a particular area with respect to the percentage of impermeable surface, i.e. GAR (Mañas et al., 2023).

From the perspective of spatial planning methodology, there arises a need to revise traditional participatory models, such as the ladder of participation, see figure 1 on page 9. New technologies like XR can create a stronger illusion of participation even where it may not truly exist, for example, through one-sided visualisations of a “final proposal” that citizens can only comment on. Therefore, higher degrees of participation should involve the possibility of making critical choices between alternatives, based on clear information and visualisations that are not manipulated by composition, viewpoint, or the suppression of controversial aspects. XR tools have the potential to become carriers of a more equitable and transparent form of spatial planning, but only if their use is regulated methodologically, ethically, and institutionally (Muehlhaus et al., 2023; Portman et al., 2015; Wolf et al., 2020). These suggestions for spatial planning process require not only technical standards for accuracy and clarity, but also procedural safeguards that guarantee impartial facilitation and prevent one-sided representations from dominating public perception. If such conditions are met, XR can support genuine deliberation by enabling citizens to compare alternatives on equal terms, fostering informed decision-making rather than reinforcing persuasive narratives (Jaalama et al., 2021; Tomkins & Lange, 2019).

This includes both technical standards, such as the obligation to display main dimensions and parameters of the design of the proposed development, and procedural principles, such as mandatory explanations from impartial mediators (Allmendinger et al., 2015; American Planning Association, 2021). Without these measures, virtualisation can easily become just another form of visual marketing in the service of power interests (Chen et al., 2022; Guttentag, 2010; Reaver, 2023). However, if planning is truly to enter the digital era as a discipline for citizens, not just for experts and developers, it is essential to accompany the development of XR tools with the development of responsibility and institutional competence that can employ their benefits to serve all equally.

THIS dissertation does not provide a closed interpretation of the topic but instead establishes a starting point for further exploration of the possibilities of using XR in spatial planning. Building on the findings obtained, the research continues as part of an international collaboration with the University of Bonn, where, during an almost year-long internship, close cooperation was established, focusing on XR technologies in public space and spatial planning, such as potential applications of AR and VR in real planning situations, with a particular focus on the qualitative aspects of perception and experience of planned changes from the perspective of residents/participants. By tracking the emotional, spatial, and interpretive reactions of participants, the aim is to uncover not only the level of understanding but also the depth of engagement that XR can elicit in participatory processes.

Based on these findings, specific and practically applicable recommendations are formulated that could serve as minimum standards for the use of XR technologies in spatial planning. These are not intended to be universal regulations, but rather a set of guidelines that reflect the need for transparency, impartiality, and clarity when working with visualisation tools. That this combination of technological innovations with a human-centred and ethically grounded approach can offer a path to move participation from a formal procedure to a space of genuine co-decision-making. This research, therefore, intends to advance knowledge in the fields of planning, ICT and also aims to strengthen the democratic dimension of planning processes in the digital age.

7

Conclusion

DISSERTATION thesis has demonstrated that the growing use of ICT in spatial planning, particularly AR and VR tools, has the potential to significantly impact the overall quality of spatial planning processes. The author has focused during his research on analysing the current state of the issue and the opportunities offered by technologies, which represent a potential for improving the shortcomings of current planning processes, when used correctly.

A main finding of this work is that meaningful and effective spatial planning requires a deep understanding of the physical characteristics of the territory and also a comprehensive insight into the needs, preferences, and lived experiences of the local community. Planning proposals leave an imprint on the places where people live, work, and spend their time, and it is therefore necessary that those who use the space today (and will use it in the future) are meaningfully considered in the process. Rather than relying solely on the voices of elected representatives or officially designated spokespersons, who may, consciously or unconsciously, interpret the present and envision the future differently from those they represent, it is important to engage directly with citizens living in the area. Their everyday experience offers a richer and more accurate picture of the territory and its potential. A clearer grasp of these local perspectives makes it more likely that the final design of a planning outcome will appropriately reflect the complexity of real needs, resulting in a vision of development that is more inclusive, grounded, relevant and, therefore, better.

This is particularly important in the Central European context, where the legacy of technocratic planning and limited participatory culture has often constrained meaningful community involvement. Bridging this gap requires informed development of spatial planning documents, but also a deeper rethinking of these institutional processes, such as including additional legally binding phases where public opinions and participatory insights would be incorporated.

Some of the results show that a higher LOI can contribute to a deeper understanding of the presented proposals, supporting more informed decision-making by citizens and enhancing the legitimacy of the resulting planning outcomes. However, it is also true that as the LOI increases, so does the risk of manipulation and distortion, both conscious and unconscious.

These technologies, therefore, open up not only opportunities but also avenues for misunderstanding and misrepresentation. It is necessary upon both creators and users of such tools to remain aware of these risks and to approach them with critical responsibility. Nonetheless, if handled carefully, immersive technologies hold real promise in making planning processes more inclusive, especially for those who might have time constraints or struggle to interpret conventional forms of spatial representation.

The synthesis of bibliometric and content analysis of scientific studies from various geographic and institutional contexts revealed that the main factor for meaningful use of ICT in spatial planning is not the technology itself, but its integration into an appropriate institutional framework and

cultural context. Successful examples highlight the importance of transparent rules, trust among stakeholders, the ability to respond to the specific needs of different groups within the population and publicly audited process for citizen feedback that can genuinely alter the decision making.

Based on the analysis, specific recommendations for practice are proposed. These include an emphasis on multi-level communication, an appropriate LOD tailored to match the visualisation method and target audience, and the introduction of ethical principles and control mechanisms to ensure the fair and non-discriminatory use of digital tools.

In conclusion, it can be stated that digital tools are not a “cure-all-drug”, but with a responsible and critical approach, they can significantly contribute to improving participation, transparency, and the quality of decision-making processes in spatial planning. This work also opens up space for further research, particularly in the area of measuring the effects of various methods of immersive participation, and exploring the long-term impacts of using XR technologies on the public’s relationship with planning processes.

Just as the development of ICT continues at a rapid pace, bringing new impulses and ideas across disciplines, spatial planning likewise benefits from the diverse and flexible ways in which these technologies can be adapted. Therefore, this dissertation is not a final destination but rather a step in continued engagement. Future focus lies in seeking out, receiving, and integrating new developments that have the potential to move spatial planning towards better and more just outcomes.

From a position shaped by both academic research and practical involvement in participatory and digital planning processes, the author remains committed to critically developing and applying immersive tools in ways that serve communities rather than manipulation.

This commitment also extends into the field of education. Teaching of future planning professionals is a crucial domain in which these technologies must be introduced, not only as technical tools, but as part of a broader critical mindset. By incorporating immersive methods into paedagogical approaches, and by encouraging students to evaluate both their potential and their limitations, educators can help foster a new generation of planners who are better equipped to deal with complex social and spatial challenges. Such training does not only expand knowledge and skills; it also cultivates professional responsibility. In the long run, this may lead to more thoughtful and lasting impacts on the territories and communities that planning ultimately seeks to shape.

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Acronyms

AR	augmented reality
AV	augmented virtuality
BCR	building coverage ratio
DI	democracy index
FAR	floor area ratio
GAR	green area ratio
GDP	gross domestic product
GIS	geographic information system
HMD	head-mounted device
HUD	head-up display
ICT	information and communication technology
LOD	level of detail
LOI	level of immersion
MR	mixed reality
OSR	open space ratio
VR	virtual reality
XR	extended reality

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