Appearances can be deceiving: The usability of photorealistic 3D geovisualisation in participatory urban planning

LUKÁŠ HERMAN[1], BARBORA PLAČKOVÁ[1], JAN MIKOLÁŠ[1], JAKUB KURA[1,2], DAJANA SNOPKOVÁ[1]

[1] Masaryk University, Faculty of Science, Department of Geography, Brno, Czechia; e-mail: herman.lu@mail.muni.cz, plackova.bar@gmail.com, mikolas.jan@mail.muni.cz, jakub.kura@iri.cz, dajana.snopkova@geogr.muni.cz

[2] Institute for Regional Information, Brno, Czechia

ABSTRACT This study investigates the usability and effectiveness of photorealistic and non-photorealistic (symbolized) 3D geovisualizations in participatory urban planning, with a particular focus on differences among user groups. In an experimental study conducted in the city of Brno, respondents from diverse backgrounds – distinguished by expertise, familiarity with the study area, age, and gender – were tasked with evaluating both visualization types for identifying land use and changes. The results revealed significant variations in preferences and task performance across user groups. Experts and men demonstrated higher task accuracy with symbolized models, which were widely regarded as more informative. On the contrary, photorealistic models were favored for fostering spatial understanding and aesthetic appeal, particularly among women and laypeople. These findings underline the importance of considering user group differences when designing visualizations, as subjective satisfaction does not always align with objective effectiveness. The study underscores the complementary roles of these visualization types and provides actionable insights into optimizing 3D geovisualizations for democratic and inclusive urban planning processes.

KEY WORDS 3D geovisualisation – participative mapping – questionnaire – urban planning – user evaluation

HERMAN, L., PLAČKOVÁ, B., MIKOLÁŠ, J. KURA, J., SNOPKOVÁ, D. (2025): Appearances can be deceiving: The usability of photorealistic 3D geovisualisation in participatory urban planning. Geografie, 130, 1, 65–91.
https://doi.org/10.37040/geografie.2025.002
Received December 2024, accepted March 2025.

1. Introduction

Even though the use of 3D visualisations is in Czechia not currently legislatively anchored in the creation of urban plans, we can find it in supporting materials, such as illustrations of building height regulations, or in urban studies, which have looser guidelines for creating map visualisations. In these cases, 3D visualisations are used mainly with the intention of facilitating the understanding of the given solved problem for the general audience, but they also go hand in hand with the modernity, innovation and aesthetics of such a visual representation. Although the use of 3D visualisations is very broad, far beyond spatial planning, the terminology, which has been discussed by Dušek, Miřijovský (2009), is still not completely stable. Bleisch (2012) defines 3D geovisualisation as a 3D visual representation of the real world, its parts, or spatially referenced data. At the same time, this corresponds to the definition of geovisualisation according to MacEachren, Kraak (2001), who describe geovisualisation as the generation of representations of digital geographic data implemented according to given rules or algorithms by means of computer graphics on displays. Further in this paper the term 3D geovisualisation will be used.

3D geovisualisation offers a powerful tool for enhancing participatory processes by providing stakeholders with a more immersive and comprehensible representation of proposed urban developments (Jaalama et al. 2021). 3D geovisualisations can play three different roles in participatory planning: (1) it can support individual information processing, for instance, to motivate and focus the attention of the viewer on extracting the relevant information, (2) stimulate various respondents' discussions, and (3) achieve the objectives of information transfer and planning tasks in different phases of the planning process, such as aiding in collecting, exploring, and analysing relevant information as well as choosing possible solutions (Jaalama et al. 2021, Marshall et al. 2024).

3D geovisualisations do not have to be used in urban planning only for analysing the current situation in the cities but also for the reconstruction of past situations or for making predictions (Konečný 2011). 3D geovisualisations can be used by both experts and the general public (Voženílek 2005, Biljecki et al. 2015), and there are both advantages and disadvantages with this movement towards 3D geovisualisations in urban planning (Judge, Harrie 2020). These contradictory foundations lead to the need to conduct empirical studies and verify or refute them.

Many applications of 3D geovisualisations of urbanised areas are related to non-photorealistic visualisation (Biljecki et al. 2015). Döllner (2007) states that non-photorealism provides sufficient means for visual abstraction as a primary technique to communicate complex geospatial information effectively. Non-photorealistic visualisation allows the implementation of cartographic methods, design principles and techniques (Döllner 2007; Häberling, Bär, Hurni 2008;

Jahnke, Krisp, Kumke 2011). On the other hand, realistic 3D geovisualisations can bridge the gap between abstract plans and tangible experiences by providing realistic representations of urban environments, including public participation purposes (Lovett et al. 2015; Onyimbi, Koeva, Flacke 2018; Judge, Harrie 2020; Jaalama et al. 2021).

While the visual appeal of the design can attract the user, it is essential to realise that this aesthetic quality, including high realism, does not necessarily correlate with functionality or usability. This cognitive dissonance between perception and objectively measured user performance presents a significant methodological limitation in urban planning and beyond. This paper explores the potential benefits and limitations of employing 3D photorealistic and non-photorealistic (symbolised) geovisualisations in urban planning, focusing on their use in participatory processes. By performing user testing, this research aims to identify the factors contributing to these visualisations' effectiveness in fostering public engagement and informed decision-making.

2. Related work

2.1. Cartographic visualisations in urban planning

Within the urban planning process (geo)visualisation plays a crucial role (Burian, Popelka, Beitlova 2018). Jaalama et al. (2021) state that 3D visuals can help people better understand the impact of new projects and make more informed decisions in comparison with flat 2D plans. These statements have been studied by several empirical studies.

Rautenbach, Coetzee, Çöltekin (2014) compared the 3D realistic geovisualisation of a city model with non-photorealistic 3D geovisualisation and a 2D map in the scope of spatial planning in South Africa. Simple map-reading tasks were solved with the same accuracy using 3D geovisualisations as using 2D maps. Herbert, Chen (2015) found that the advantages of 3D geovisualisation included the added contextual information of visualising the proposal within the urban space, shadow effects, and the ability to navigate through the environment. Similarly, Onyimbi, Koeva, Flacke (2018) compared 2D maps and plans with realistic 3D models in participatory spatial planning. In their evaluation, higher accuracy was achieved when working with a 3D geovisualisation.

The fundamental challenge for designing, developing and implementing 3D geovisualisations in urban planning, as well as beyond, is to avoid complexity and too much detail (Carneiro 2008). 3D geovisualisation, in terms of the amount of visual information, can be characterised through the level of detail (LoD) and the level of realism (LoR). The LoD corresponds to degrees of spatial abstractions of 3D spatial data, especially the amount of geometric details (Open Geospatial Consortium 2024), while the LoR refers to a scale of visual appearance and photorealism (Fila, Štampach, Stachoň 2024).

LoD and LoR can enhance the visual appeal and informativeness of 3D geovisualisations, on the other hand, there is a trade-off between these factors and computational cost, as well as potential cognitive overload for users (Lokka, Çöltekin 2019). Chassin et al. (2022) found that simpler LoD outperformed more complex ones in their user study. They attributed this to the fact that higher levels of abstraction or focusing on salient features reduced the time needed to complete tasks. On the other hand, a user study by Doula et al. (2022) demonstrated that a higher LoD improved landmark identification. In the middle between those conclusions are the results of Gardony, Hendel, Brunyé (2022), who found that a moderate LoD is sufficient for users to navigate and understand spatial relationships. LoR is determined mainly by texture information (Lee & Yang 2019). Kibria et al. (2009) stated that higher realism, as well as LoD, enhances the user's linear perception of understanding the design of an object in 3D geovisualisations.

Particular recommendations regarding non-photorealistic visualisation are formulated, for example, by Gatzidis, Brujic-Okretic, Mastroyanni (2009). They identified that non-photorealistic shading and especially expressive rendering could provide more effective visual styles than photorealistic representations of built-up areas. The results of Chassin et al. (2022) also demonstrate that an absence of textures reduces the time needed to solve spatial tasks, namely estimation of building heights, estimation of visibility and assignment of the corresponding 2D floor plan. Popelka, Dědková (2014) found a less efficient search in the case of a textured 3D model, too. They infer this statement from the greater number of fixations recorded using eye-tracking. In this study, a textured 3D model of the village was compared with an aerial photograph and a cadastral map.

In addition to studies that compared photorealistic visualisations with their alternatives, the specific content and content of photorealistic visualisations is also a researched topic. That is the effort to prioritise individual classes of elements within the framework of 3D geovisualisation of built-up areas. Bandrova, Bonchev (2013) state that the respondents of their questionnaire survey would expect textured buildings and terrain, as well as representation of roads and vegetation, within the large (detailed) scale 3D geovisualisations. The urban furniture and similar smaller objects were identified as less important (Bandrova, Bonchev 2013).

In Czech practice, 3D geovisualisation methods are not legally anchored in the urban planning process, and this remains unchanged even after the legislative amendments introduced by the new Building Act No. 283/2021 Coll. (2021). and its implementing decrees. While this legislation marks a significant step towards the digitization of urban planning at all hierarchical levels, the entire practice continues to rely on a two-dimensional approach. The Building Act strictly defines the format and structure of urban plan drawings, leaving room for 3D methods mainly in supporting materials or to visualise spatially relevant topics. For example, 3D city models, increasingly common in regional capitals, are used to establish building height regulations – an important topic in larger cities. Notable applications include Prague's Metropolitan Plan, displayed through a 3D model of Prague (Institute of Regional Planning Prague 2024).

Entire urban plans can also be transferred into 3D, though this approach is rare in Czech practice, with only a handful of municipalities adopting it, such as Rakovice's urban plan, which includes both a mandatory 2D version and additional 3D version (Deník veřejné správy 2019). On the other hand, urban studies may represent a promising domain for the application of 3D geovisualisation methods, as their format is not strictly regulated by legislation apart from a few requirements regarding the graphical representation of standardized elements. It is common practice in the Czechia for urban studies to include schematic 3D depictions of the area under consideration and its integration into the broader context, providing a clearer picture of how the area will look following the implementation of proposed interventions (Atelier proREGIO s. r. o. 2023). Therefore, urban studies are arguably the most suitable platform for leveraging 3D technologies. However, the challenge in public participation, as the legislation does not mandate the involvement of citizens in the preparation of such studies. These studies require approval only by the municipal council, and the public's role depends on the extent to which debate is allowed in council meetings. Nevertheless, Czech practice shows that citizens often can provide feedback on such studies during this phase.

2.2. Public engagement

Cities are increasingly adopting 3D models to represent their urban environments. These models provide a more accurate and immersive geovisualisation of planning initiatives, allowing for a better understanding of height, scale or proposed changes. Therefore, 3D geovisualisation also has an important role in participatory urban planning (Billger, Thuvander, Wästberg 2017; Marshall et al. 2024). In general, the possibilities of public participation have been accelerated by web-based technologies (Marshall et al. 2024). During the last 20 years, several solutions for participatory planning based on 3D geovisualisation have been created. For instance, Levend, Fischer, Thomas (2023) developed a decision support framework based on a 2D and 3D geovisualisation and analytic hierarchy process.

The practical application of 3D geovisualisation in participatory planning can be found in combination with Public Participation Geographical Information Systems (PPGIS), which are closely related to the concept of Volunteered Geographic

Information (Fagerholm et al. 2021, Hasanzadeh et al. 2023). PPGIS surveys enable individuals and groups to engage in spatial planning or decision-making actively with the support of GIS technologies, and thereby promote their interests and priorities (Denwood, Huck, Lindley 2022). Respondents mark geometric features on the map of the area of interest about the surveyed topics, and in some cases, they also can comment on their choices. The values recorded may represent spatial behaviour patterns, attitudes or preferences (Fagerholm et al. 2021). In general, the aim is to keep the whole process simple and easy to adopt for the participants so that the general public, as well as planners outside the academic sphere, can be involved (Hasanzadeh et al. 2023). 3D geovisualisations can be helpful for this purpose, allowing participants to easily virtually explore the environment, enhancing their sense of presence and understanding of the meanings and contexts of places (Jaalama et al. 2021). A pilot study using 3D geovisualisation in combination with PPGIS was carried out by Hasanzadeh et al. (2023). Respondents used point markers that they placed in an online mapping survey to identify locations and suggest ways to develop them in the future.

Public participation in urban planning in Czechia operates within a clearly defined legislative framework, specifying when and how the public can engage in the process. For urban plans, public participation is permitted during the phase of collecting proposals for the urban plan changes and later during the Public Proceedings phase. However, there is no guarantee that public comments will be incorporated into the final plan as it is the municipal council's decision. Ideally, participatory urban planning should be a democratic process that covers the heterogeneity of tasks, contexts and purposes (Marshall et al. 2024). However, there are only a few studies which validate these tasks, contexts and purposes through usability evaluations (Eilola et al. 2023). Hasanzadeh et al. (2023) mention that altitude, as the third dimension, has often been absent from participatory planning research and practice, although we naturally experience the environment in 3D. The third dimension allows better capture of vertical features such as height differences between buildings and terrain, leading to more detailed markings from respondents, for example at different building heights. Respondents may find 3D geovisualisations more user-friendly and easier to understand, which may also increase their engagement and quality of feedback compared to traditional 2D maps.

Regarding practical recommendations for participatory planning based on 3D geovisualisation, Chassin et al. (2022) suggest combining 3D with other methods to collect the contribution of study respondents to limit bias in the decision and to increase the inclusivity of the approach. The main motivation for this combination was problems with interaction with 3D geovisualisations (Chassin et al. 2022). Similarly, Judge, Harrie (2020) recommends avoiding overwhelming the participant with the possibilities of interaction design and, therefore, recommends simplifying the control as much as possible.

Hayek (2011) found that during participatory planning workshops, the most suitable areas for the application of 3D geovisualisation are motivation, communication of information for analysis, the gathering of new information and evaluation. On the contrary, Hayek (2011) did not prove if 3D geovisualisation supports the development of new ideas or decision-making. Judge, Harrie (2020) also draws attention to a possible problem with the use of 3D geovisualisation for illustrating plans or future variants because there can be significant differences between what a 3D geovisualisation shows and how it might manifest. Highly detailed 3D geovisualisation was identified as increasing this false perception.

To sum up, improving the only technology is not necessarily enough to improve public participation (Judge, Harrie 2020). For these reasons, we want to investigate user aspects, specifically the effect of the level of realism on decision-making in spatial planning. Specifically, we want to focus on tasks related to the communication of information for understanding the planning area and/or scenarios (Eilola et al. 2023) and for analysis (Hayek 2011).

3. Methodology

3.1. Research objectives

Addressing open challenges from the literature review, we designed an original experimental study comparing the usability of both photorealistic and non-photorealistic (hereinafter referred to as symbolised) 3D geovisualisation for urban planning purposes. We employed interactive 3D geovisualisations, which address a wider spectrum of participatory spatial planning tasks. The city of Brno was chosen as the study area, so data from a 3D model of Brno buildings – Brno City Chief Architect's Office (KAM) 2019 – was used to create 3D geovisualisations for the experimental usability testing. We wanted to include the widest possible spectrum of users in the testing, with varying degrees of expertise in the field of spatial planning.

We formulated the following research questions (*RQ*) for the study in line with the results of the aforementioned studies:

- RQ1: How effective is a photorealistic 3D geovisualisation compared to a symbolised 3D geovisualisation when identifying land use type and changes?
- RQ2: How is a photorealistic 3D geovisualisation subjectively evaluated compared to a symbolised 3D geovisualisation when identifying land use type and changes?
- RQ3: What are users' priorities regarding the content of photorealistic models?

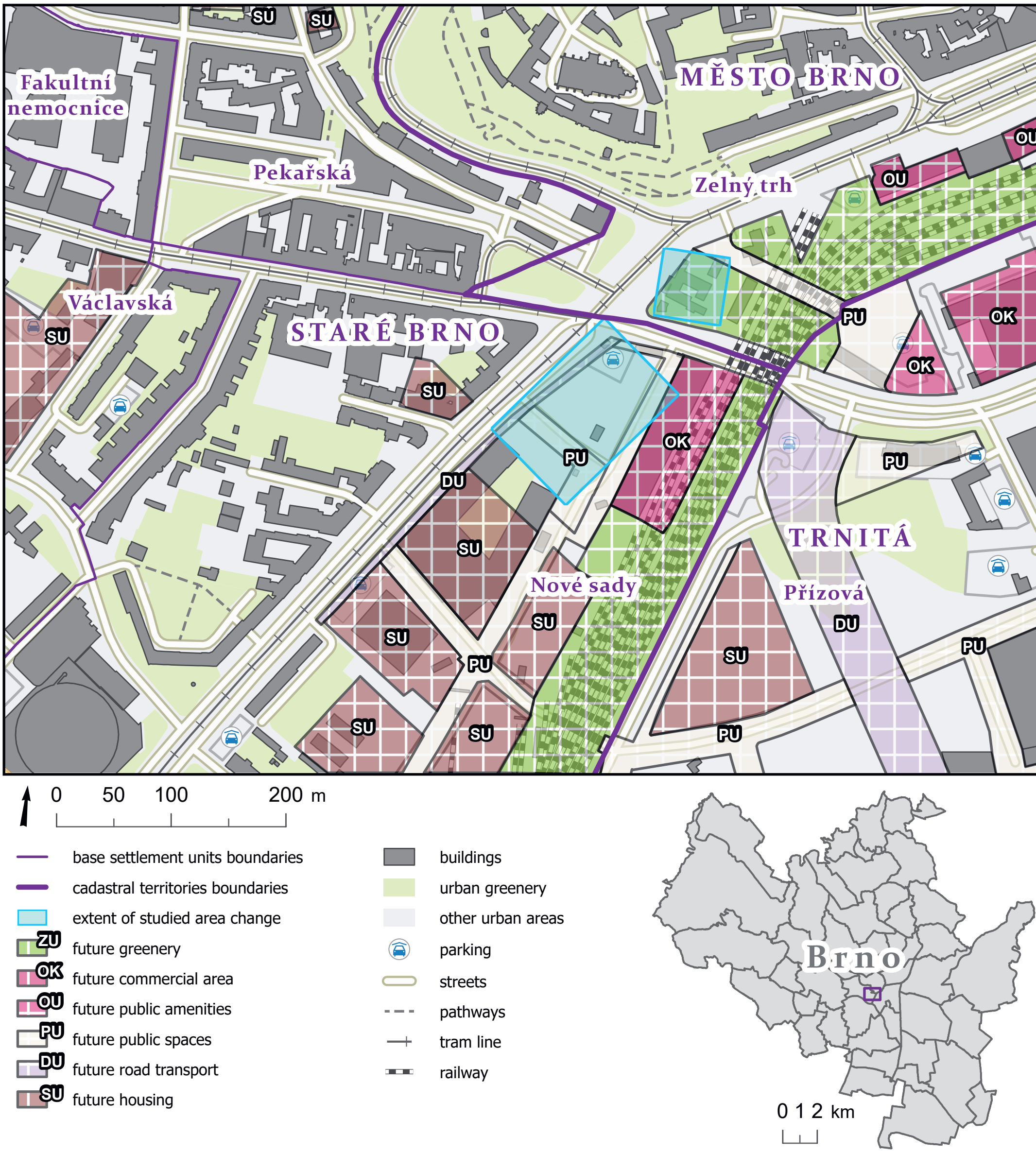
RQ1 goes straight to the core of the studied issue: What type of 3D geo-visualisation is more effective for conveying information about the urban environment? Effectiveness will be examined as the correctness of user responses (ISO 2019). We employed spatial tasks to assess the effectiveness, namely tasks aimed at classifying functional areas and tasks aimed at identifying changes in land use. Classifying functional areas is a part of the basic spatial understanding (Juřík et al. 2018). Identifying changes in land use is crucial to planning future development and distinguishing between changing and stable territories, an issue previously analysed by Judge, Harrie (2020). Both tasks can be considered a part of information communication to better understand the planning area and/or scenarios (Hayek 2011; Eilola et al. 2023). *RQ1* was defined based on conflicting conclusions of several studies (Chassin et al. 2022; Doula et al. 2022; Fila, Štampach, Stachoň 2024; Gardony, Hendel, Brunyé 2022; Häberling, Bär, Hurni 2008; Judge, Harrie 2020; Kibria et al. 2009; Lee, Yang 2019).

The subjective users' evaluation is also important to understand how they perceive and work with different types of visualisations, which is why *RQ2* was defined. Subjective assessments or attractiveness were also previously investigated, for example, by Judge, Harrie (2020), Chassin et al. (2022), or Fila, Štampach, Stachoň (2024). Both *RQ1* and *RQ2* will be analysed for all respondents and at the level of groups of users, which we distinguished based on respondents' familiarity with the studied area (previously by Jaalama et al. 2021), their level of expertise, age, and gender (Chassin et al. 2022). Usability analysis on the level of groups of users is related to the democratisation of urban planning; thereby contributing to a more inclusive spatial planning process (Marshall et al. 2024) when it can be assumed that a more democratic 3D geovisualisation will be perceived similarly attractive and be similarly efficient for more user groups.

In addition to *RQ1* and *RQ2*, we want to investigate the requirements and opinions on the content of photorealistic 3D geovisualisation, similar to research made by Bandrova, Bonchev (2013) or Gatzidis, Brujic-Okretic, Mastroyanni (2009). Therefore, *RQ3* was defined.

3.2. Study area

The selected study area, Nové sady, covers approximately 62 hectares in the city centre of Brno (Czechia), spanning six basic settlement units: Pekařská, Zelný trh, Přízová, Nové sady, Václavská, and Fakultní nemocnice, see Figure 1. In Czech cities, basic settlement units are defined as continuous parts of the municipality's territory with a certain character or predominant function. They may represent individual neighbourhoods, urban parts, sites with local names or areas with a predominant use other than housing (Czech Statistical Office 2025). The study



November 2024, Data: ZABAGED® ČÚZK, [2024], © OpenStreetMap contributors

Fig. 1 – Map of the study area used in the questionnaire

area mainly consists of stabilised general residential zones and mixed-use central zones, with arterial roads featuring 2 or 3 lanes and multilevel junctions with public transport routes. It also includes buildings listed in the central register of cultural monuments (Petrov, Malá Amerika) with protected green infrastructure. This part of the city of Brno was selected for the anticipated changes in land use, including possible new construction here. Brno was chosen because of the frequent discussions on spatial planning, with the new spatial plan being prepared for almost 30 years.

The 3D geovisualisations were intentionally based on an area with brownfields meant for revitalisation to represent both current and future states. The proposed changes include urban green infrastructure (parks), mixed-use zones (central character), and general residential zones. The proposed future changes were focused on highlighted areas within Nové sady and Zelný trh; see Figure 1. These are simulated changes, not actual proposed conditions, illustrating potential depictions only.

3.3. Preparation of 3D geovisualisations

3D models of the study area in the current and proposed (future) state were created for user testing purposes. Furthermore, both types of visualisations mentioned above were created, namely non-photorealistic (symbolised) and photorealistic (textured). In total, four variants of the 3D model were created, see Figure 2. The categorisation of objects was derived from the procedures outlined by Judge, Harrie (2020) and Herbert, Chen (2015).

The following spatial data were used to create the 3D models:

- Elevation contour lines at 1 m intervals (Statutární město Brno 2022) were used for the creation of a digital terrain model on which all other objects were placed.
- The 3D buildings model in LoD2 (Open Geospatial Consortium 2024) of Brno provided by the GIS department of the Municipality of Brno (geodatabase with Multipatch geometry).
- The urban plan from 1994 (Magistrát města Brna Oddělení GIS 2024a) as well as the one, that was being prepared (Magistrát města Brna Oddělení GIS 2024b) were used as a georeferenced background, which was subsequently vectorized.
- The Orthophoto of the Czechia created and distributed by Czech Office for Surveying Mapping and Cadastre (2024) was used as a basis for drawing transport line elements, (tram and train tracks, major roads), and selected areas, e.g., parking sites.

The Mapy.cz portal was also used to check and improve the positional localisation of the created objects. Additional object models (vehicles, construction machines,

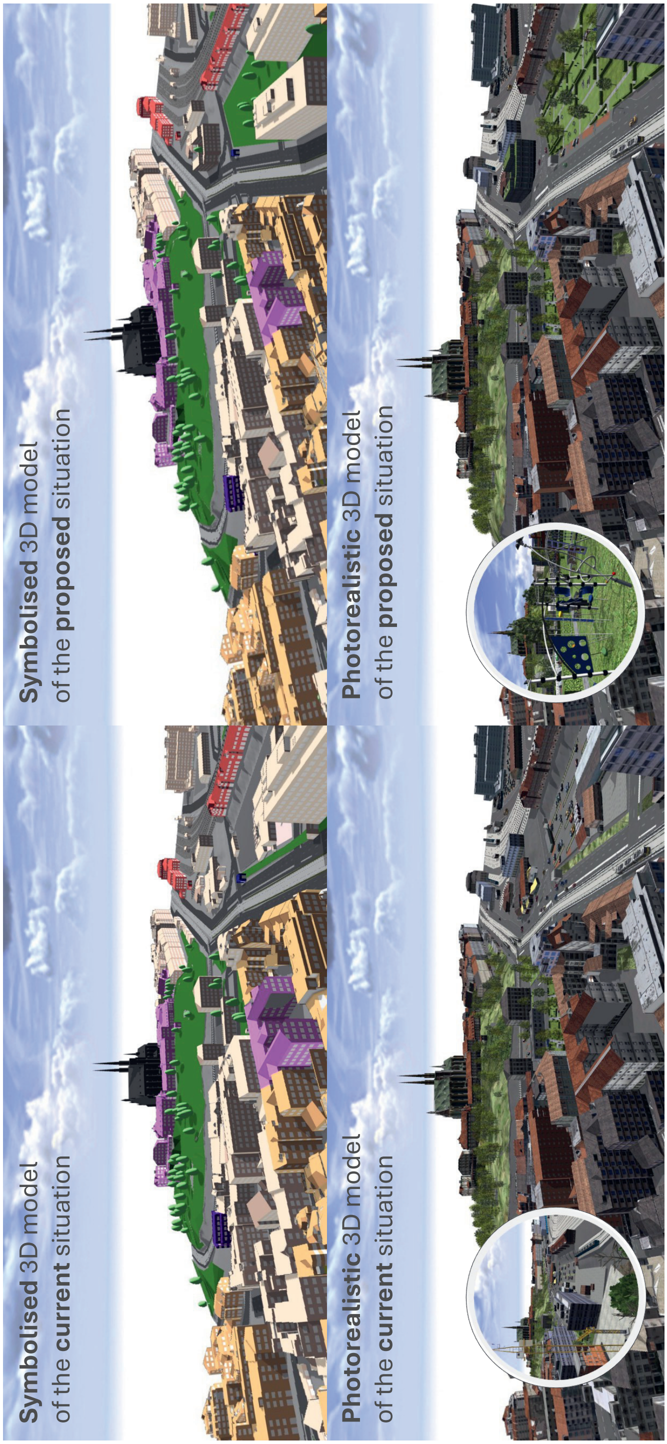


Fig. 2 – Screenshots from four created 3D models

playgrounds, benches, people, railings, etc.) were added to the photorealistic model variants. Data pre-processing took place in the ESRI ArcGIS Pro; the ArcGIS City Engine was used to create the 3D model itself. The "Rule package" for procedural modelling in ArcGIS City Engine was used from the Esri.lib library, which contains many of these packages with various features for rendering objects (vegetation, vehicles, buildings, textures). The final outputs are four models; see Figure 2, that are presented as a so-called "360 VR Experience" in the ArcGIS 360 VR web application, which allows the user to switch between set views (marked as "Bookmarks") and rotate within them. Thus the user is not overwhelmed by the interaction, which Judge, Harrie (2020) and Chassin et al. (2022) identify as a possible problem. The used technology does not require the installation of any special software or plug-ins and runs in a common web browser.

3.4. User evaluation questionnaire

For verifying the suitability of both types of created models in the practical public participation in the spatial planning process, a simple online questionnaire was created using Google Forms. The full wording of the original online questionnaire in the Czech language is published on Figshare (Plačková 2025). The questionnaire's introduction includes among others request to complete the questionnaire on a laptop or desktop computer. The questionnaire obtained basic identification information about the respondents (Q1–6), several practical tasks based on the created 3D models (Q7–11, 14–17, and 19), and subjective assessment (Q12, 13, 18, and 20–33). As both models differ in their nature in terms of the amount of information contained, the questions for each model were slightly different. A detailed structure of the questionnaire is illustrated in Figure 3. The questionnaire contained hyperlinks to individual variants of interactive 3D models in the ArcGIS 360 VR.

The experiment followed a within-subject design, where each user worked with both models and answered all questions in a fixed order. The questionnaire was distributed through the social platform Facebook to groups of specialised experts (planners, surveyors, architects, cartographers) and students at the Brno University of Technology Faculty of Architecture. It was also sent to the public to compare the sample with laypersons.

4. Results

The questionnaire was filled out altogether by 100 people (61% men and 39% women), usually in the age category 18–24 (58%), 30–39 (15%), and then 25–29 (14%). A small sample of respondents under 18 (3%) and over 50 (3%) was also taken. For

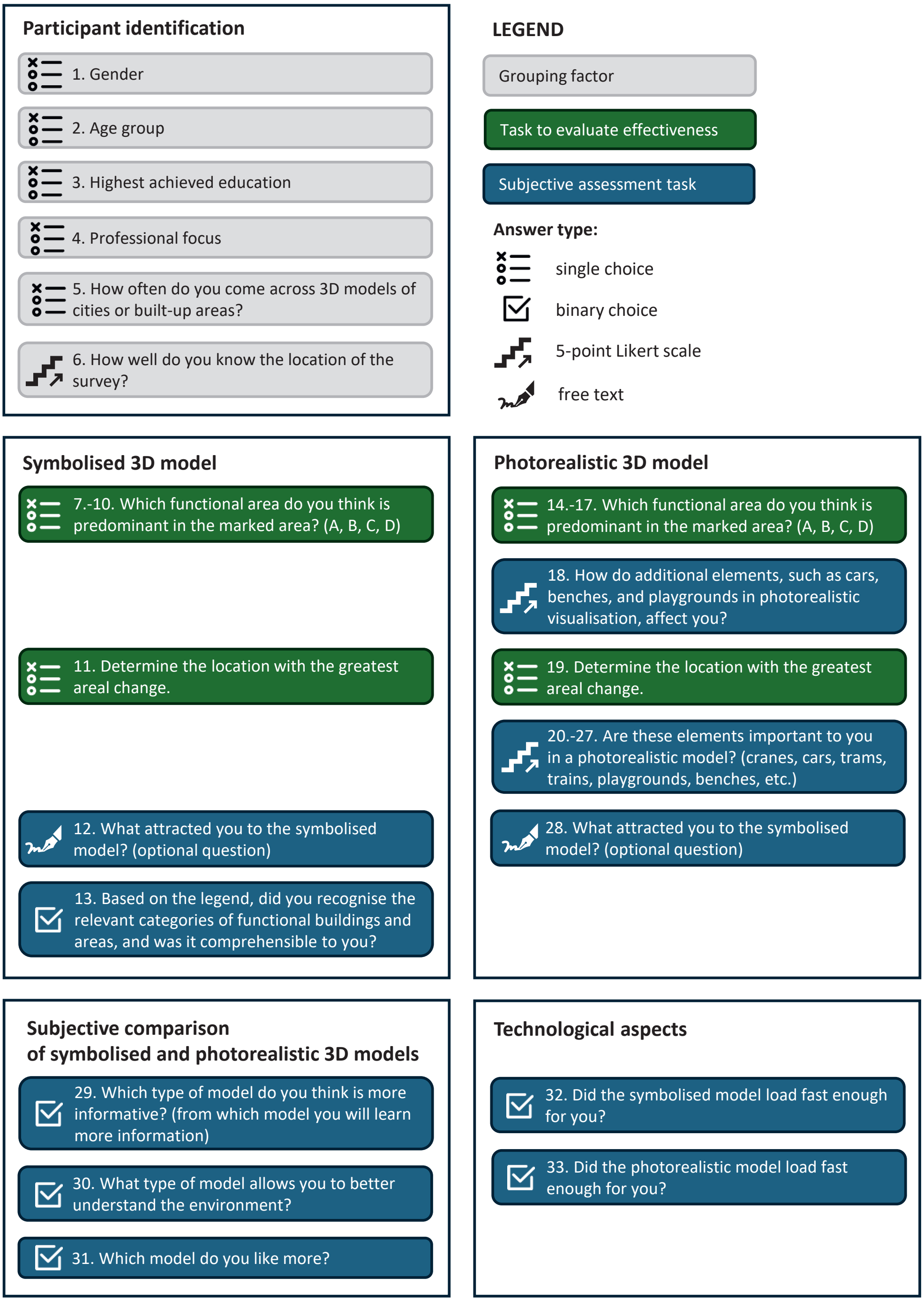


Fig. 3 – Structure of the online user evaluation questionnaire

the purposes of further processing, the respondents were divided into two groups with an age limit of 30 years. A high school graduation was most often mentioned (58%) as the highest achieved level of education, followed by a university degree (32%), elementary school (7%), and high school with no diploma (3%). Regarding expertise, 62% of respondents were classified to have cartographic knowledge (experts) and the remaining 38% were identified as laypersons. Respondents stated that they encounter 3D models of cities rather occasionally (44%) or rarely (35%), only a minority regularly (12%) or daily (3%), and 6% of respondents never encountered a 3D model before. The familiarity with study location was approximately normally distributed; "familiar" and "unfamiliar" groups consisted of people who voted "Agree" and "Strongly Agree" and "Strongly Disagree", "Disagree", and "Neutral" on the Likert scale, respectively.

4.1. Effectiveness (RQ1)

Based on the user evaluation questionnaire, we were able to assess the effectiveness of the decision-making of the respondents based on the correctness of their responses in two types of tasks. In the first type, the classification task (Q7–10, 14–17), respondents determined the type of buildings, respectively the type of highlighted functional areas. In the second type, the land use area change task (Q11 and Q19), they identified the area with the greatest change. For the fourth classification task (Q17) in the case of the photorealistic model, in the end, two options were marked as correct.

Both models seem to be equally effective for both task types. In the case of the classification task, the average success rate of the respondents using the symbolised 3D model reached 90.50% (min = 25%, max = 100%, med = 100%, sd = 0.2003), and photorealistic 3D model 87.25% (min = 25%, max = 100%, med = 100%, sd = 0.1863). For the land use area change task, the success rate was again almost the same for both models (symbolised: mean = 64.00%, min = 0%, max = 100%, med = 100%; photorealistic: mean = 63.00%, min = 0%, max = 100%, med = 100%). Further, we focused on the results for individual groups of respondents and the differences between them regarding the use of symbolised and photorealistic 3D models. Descriptive statistics are summarized in Table 1 and Figure 4.

Considering gender, in the classification task, men consistently performed better than women in both model types. For the symbolised 3D model, men achieved a mean success rate of 94.67%, while women had 83.97%. Similarly, for the photorealistic model, men's mean success rate was 89.75% compared to women's 83.33%. In the land use area change task, men also outperformed women, particularly when using the symbolised model (mean success rate: men: 74.59%, women: 51.28%). This was actually the biggest identified difference between groups. However, the

Table 1 – Descriptive statistics of task correctness

		OVERALL Task correctness				
		min (%)	max (%)	mean (%)	med (%)	sd
Symbolised 3D model	Building classification tasks	25	100	**90.50**	100	0.2003
	Land use area change task	0	100	**64.00**	100	0.4824
	All tasks	20	100	**85.20**	100	0.2002
Photorealistic 3D model	Building classification tasks	25	100	**87.25**	100	0.1863
	Land use area change task	0	100	**63.00**	100	0.4852
	All tasks	40	100	**82.40**	80	0.1826

		Task correctness by GENDER									
		women					men				
		min	max	mean	med	sd	min	max	mean	med	sd
Symbolised 3D model	Building classification tasks	25	100	**83.97**	100	0.2532	25	100	**94.67**	100	0.1452
	Land use area change task	0	100	**51.28**	100	0.5064	0	100	**72.13**	100	0.4521
	All tasks	20	100	**77.44**	80	0.2392	20	100	**90.16**	100	0.1533
Photorealistic 3D model	Building classification tasks	25	100	**83.33**	100	0.2171	50	100	**89.75**	100	0.1606
	Land use area change task	0	100	**64.10**	100	0.4860	0	100	**62.30**	100	0.4887
	All tasks	40	100	**79.49**	80	0.2025	40	100	**84.26**	80	0.1678

		Task correctness by EXPERTISE									
		laypeople					men				
		min	max	mean	med	sd	min	max	mean	med	sd
Symbolised 3D model	Building classification tasks	25	100	**82.24**	100	0.2460	25	100	**95.56**	100	0.1469
	Land use area change task	0	100	**63.16**	100	0.4889	0	100	**64.52**	100	0.4824
	All tasks	20	100	**78.42**	80	0.2296	20	100	**89.35**	100	0.1688
Photorealistic 3D model	Building classification tasks	25	100	**80.26**	75	0.2263	50	100	**91.53**	100	0.1427
	Land use area change task	0	100	**68.42**	100	0.4711	0	100	**59.68**	100	0.4945
	All tasks	40	100	**77.89**	80	0.1961	40	100	**85.16**	80	0.1696

		Task correctness by AGE									
		younger (< 30)					older (> 30)				
		min	max	mean	med	sd	min	max	mean	med	sd
Symbolised 3D model	Building classification tasks	25	100	**90.00**	100	0.2175	50	100	**92.00**	100	0.1392
	Land use area change task	0	100	**65.33**	100	0.4791	0	100	**60.00**	100	0.5000
	All tasks	20	100	**85.07**	100	0.2133	40	100	**85.60**	80	0.1583
Photorealistic 3D model	Building classification tasks	25	100	**86.67**	100	0.1898	50	100	**89.00**	100	0.1780
	Land use area change task	0	100	**61.33**	100	0.4903	0	100	**68.00**	100	0.4761
	All tasks	40	100	**81.60**	80	0.1824	40	100	**84.80**	100	0.1851

		Task correctness by FAMILIARITY WITH STUDY AREA									
		familiar					unfamiliar				
		min	max	mean	med	sd	min	max	mean	med	sd
Symbolised 3D model	Building classification tasks	25	100	**91.28**	100	0.2033	25	100	**89.91**	100	0.1997
	Land use area change task	0	100	**65.12**	100	0.4822	0	100	**63.16**	100	0.4867
	All tasks	20	100	**86.05**	100	0.2162	20	100	**84.56**	80	0.1890
Photorealistic 3D model	Building classification tasks	50	100	**90.12**	100	0.1650	25	100	**85.09**	100	0.1997
	Land use area change task	0	100	**65.12**	100	0.4822	0	100	**61.40**	100	0.4911
	All tasks	60	100	**85.12**	80	0.1518	40	100	**80.35**	80	0.2017

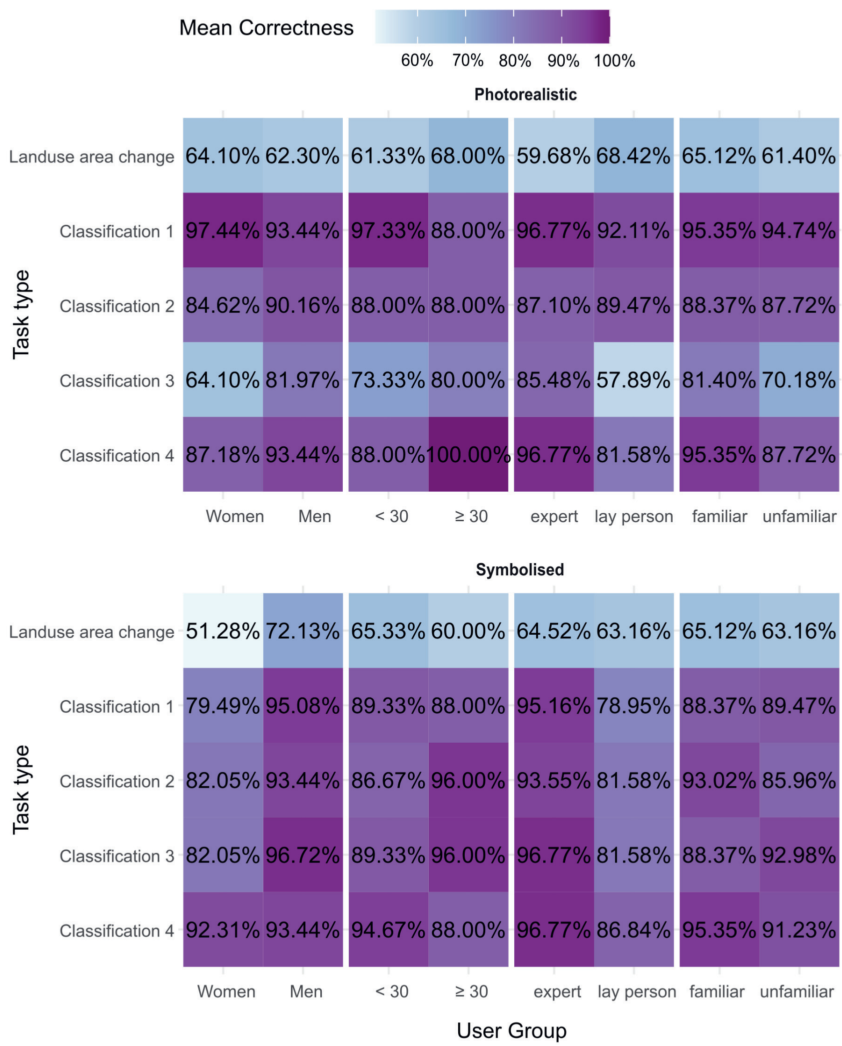


Fig. 4 – Mean task correctness rates (by user group and model type). Note that for the Classification 4 task, eventually, two answers were correct.

disparity was smaller for the photorealistic model, where women slightly exceeded men (mean correctness: women: 64.10%, men: 62.30%).

When we look at the different expertise of the respondents, in the classification task, experts performed better than laypersons for both models. For the symbolised model, experts reached a mean success rate of 95.56% compared to laypeople's 82.24%. In the photorealistic model, experts again had a higher mean success rate of 91.53%, while laypersons reached 80.26%. In the land use area change task, laypersons slightly outperformed experts when using the photorealistic model (laypersons: 68.42%, experts: 59.68%), while both groups demonstrated similar performance when using the symbolised model (laypersons: 63.16%, experts: 64.52%).

When differentiating respondents by age, in the classification task, older respondents (> 30) had a slightly higher success rate than younger ones (< 30), particularly for the symbolised model (older: 92.00%, younger: 90.00%). For the photorealistic model, older respondents maintained a marginal advantage (older: 89.00%, younger: 86.67%). In the land use area change task, younger respondents performed slightly better when using the symbolised model (younger: 65.33%, older: 60.00%), while older respondents did better when using the photorealistic model (older: 68.00%, younger: 61.33%).

Considering the familiarity of respondents with the study area, in the classification task, familiarity with the study area led to a marginal increase in performance. Respondents familiar with the area had higher mean success rates in both models (symbolised: 91.28%, photorealistic: 90.12%) compared to respondents unfamiliar with the area (symbolised: 89.91%, photorealistic: 85.09%). In the land use area change task, those familiar with the study area achieved a higher success rate with the symbolised model (familiar: 75.58%, unfamiliar: 63.16%). However, in the photorealistic model, both groups showed similar performance (familiar: 65.12%, unfamiliar: 61.14%).

These findings indicate some group-specific tendencies, with men, experts, and familiar respondents showing higher success rates in classification tasks across both models. However, younger respondents and laypersons demonstrated comparable or better performance in land use area change tasks, especially in photorealistic models. The photorealistic 3D model showed smaller differences in performance when compared to gender and expertise groups. On the contrary, age groups had smaller differences in performance when working with symbolised 3D geovisualisation.

4.2. Subjective assessment (RQ2)

The effectiveness of task solving is an objective means of assessing the suitability of photorealistic and symbolised 3D models for solving tasks relevant to participatory urban planning. However, we also analysed the respondents' subjective evaluation of 3D models, which can diverge from their performance (Chassin et al. 2022; Fila, Štampach, Stachoň 2024). Respondents were subsequently asked to select a model which they considered more informative (Q29), better for understanding the environment (Q30), and more likeable from the aesthetics perspective (Q31).

Overall, 75% of respondents considered the symbolised 3D model to be more informative than the photorealistic model. However, 55% of them considered the

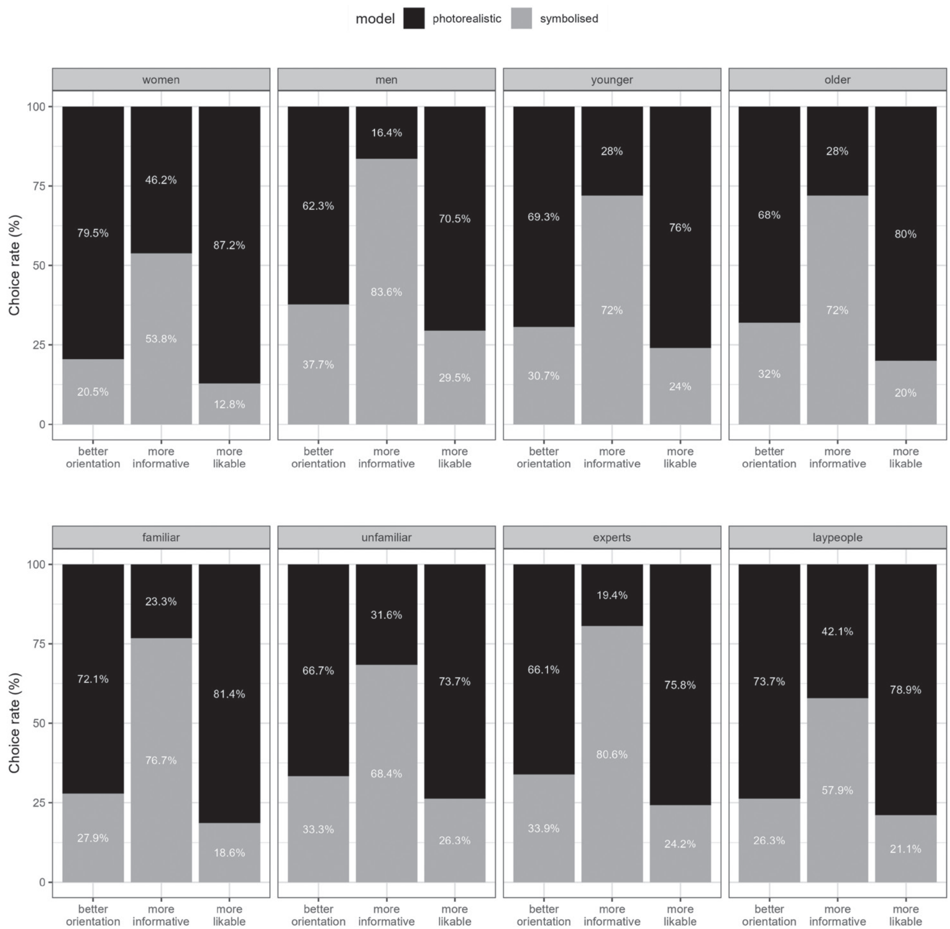


Fig. 5 – Comparison of symbolised and photorealistic 3D model suitability for information, ease of orientation (spatial understanding), and attractiveness purposes

photorealistic model better regarding understanding of the environment, and even more of them (69%) stated that they liked it more. Further, we also focused on the variation of subjective opinions inside individual groups of respondents. Responses are summarised in Figure 5.

Most men (83.6%) considered the symbolised 3D model more informative, while women were more indecisive (53.8% of them voted for the symbolised model). A similar trend can be observed also by experts and laypeople, where 80.6% of experts and only 57.9% of laypeople considered symbolised 3D models to be more informative. From the point of view of assessing the suitability of the model for understanding the environment, the biggest difference in preferences was found between men and women, when the photorealistic model was preferred by 62.3% of men and 79.5% of women. From the point of view of the overall appearance and aesthetics of the 3D models, of all the groups, women had the strongest preference (87.2%) for the photorealistic model, while only 70.5% of men preferred it as opposed to the symbolised 3D model. Different respondents' ages did not play a role in the subjective evaluation of 3D models.

In analysing respondents' responses about what attracted them to symbolised (Q12) and photorealistic 3D models (Q28), clear distinctions in attractiveness and utility emerged. The symbolised model was praised for its simplicity and clarity, with users appreciating the use of colours and shading to differentiate building functions, as well as the ease of orientation (spatial understanding) provided by a structured legend and distinct colour-coded categories. Comments highlighted how the model's straightforward design made it visually appealing and practical for spatial comprehension, drawing comparisons to minimalist designs.

In contrast, the photorealistic model received a commendation for its realism and detail. Respondents noted the immersive quality of textures and shadowing, which contributed to a sense of authenticity and allowed for an in-depth spatial understanding. The realistic representation of vegetation, furniture, and dynamic elements (people or vehicles) provided a lifelike context, enhancing users' ability to imagine the space as it might exist in reality. Overall, while the symbolised model facilitated conceptual understanding, the photorealistic model offered a nuanced experience that fostered emotional engagement and a realistic interpretation of the urban environment.

4.3. Content of photorealistic visualisation (RQ3)

From the methodological point of view of the creation of photorealistic 3D models, we were also interested in the added value of additional graphical elements (Q18), specifically vegetation, playgrounds, cars, people, benches, railing, traffic signs, and construction elements. Overall, 48% of respondents considered these elements to be "enriching" and 30% more "rather enriching". No one considered them to be "completely unnecessary", and only 7% considered them "rather unnecessary". Only two respondents mentioned (Q28) that they would not call the presented model photorealistic. According to them, this model is somewhat far from their perception of the term photorealistic. However, the vast majority of respondents stated that this model seemed really realistic to them or like a video game.

Further, we also focused on which added graphical elements are the most important according to the respondents (see Figure 6). Almost all respondents (96%) considered vegetation to be an important element in the photorealistic 3D model.

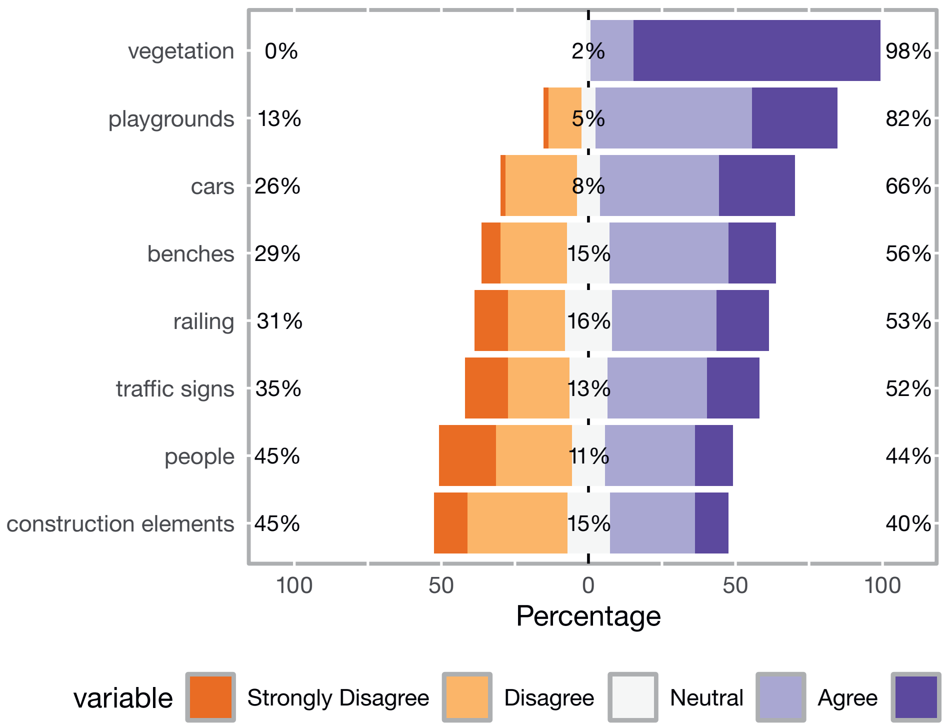


Fig. 6 – Evaluation of the importance of different detailed elements added to the photorealistic model

The majority also voted for playgrounds (83%), cars (68%), and benches (63%). They were indecisive about stair railings (51%), traffic signs (50%), and construction elements (46%). Surprisingly, people were not considered as an important feature of the 3D model by most respondents. We also checked for variability in the responses for individual groups of respondents, but the responses were more or less consistent across all groups. Vegetation, playgrounds, cars, and benches all ranked in the top four. Cars, playgrounds, and benches are a bit more important elements for laymen than experts, probably because of better identification of the function of urban green spaces or the traffic intensity on roads.

5. Discussion

By comparing *RQ1* and *RQ2*, this study sought to understand both the objective and subjective dimensions of user experience with both symbolised and photorealistic 3D geovisualisation. If we focus on the overall assessment of correctness for all spatial tasks (Q7–11, 14–17, 19), we find that it was higher in the case of symbolised visualisation (90.50%). The correctness of solving the task using photorealistic visualisation was only slightly lower overall (87.25%). Even from the point of view of evaluating informativeness, users preferred symbolised visualisation (75%). On the contrary, for spatial understanding, respondents slightly preferred photorealistic visualisation (55%). An even more significant difference occurred in the case of likability, where a total of 69% of respondents preferred photorealistic visualisation.

The colour differentiation of buildings or land use areas in the symbolised model is indeed beneficial from the point of view of quickly classifying the specified area into the predetermined category of the legend. However, what is in this space can be imagined better by those who understand what falls into these categories or who know the area well. They did not refute our results, but they did not confirm this either. Symbolised visualisation was more effective for both groups, which were divided based on local knowledge. For those users who stated that they did not like the location at all, this difference compared to the photorealistic visualisation was even greater than for those who knew the area.

At the same time, a symbolised (and simplified) form of 3D geovisualisation is more suitable for some users because they do not feel overwhelmed by visual information; additional objects or textures are not so important to them. In our case, this difference was especially evident in the group of experts (89% overall correctness for symbolised visualisation, 85% for photorealistic). The subjective assessment of informativeness turned out similarly, namely 81% favouring symbolised visualisation. This corresponds to the conclusions of Häberling, Bär, Hurni (2008), who state that professionals prefer symbolic visualisation. An even slightly larger difference was seen in the case of the men category (90% overall correctness for symbolised visualisation, 84% for photorealistic). The subjective assessment of informativeness turned out similarly, namely 83% favouring symbolised visualisation. It is likely that these user groups can work more effectively with a more abstract form of visualisations. The perception of the informativeness of different types of 3D geovisualisations can be quite subjective. Some groups of users may perceive the added information mainly in the displayed land use categories of the symbolised geovisualisation and may consider this type of depiction to be more authoritative. These users may perceive the photorealistic model only as an image. On the contrary, others may see the added value in the richer textures of the photorealistic model. Future research is, however, needed to explore this user aspect in more detail.

Regarding the *RQ3*, we came to similar results as Bandrova, Bonchev (2013), when vegetation was identified as one of the most important elements of photorealistic geovisualisation, and other elements such as urban furniture (playgrounds, benches) were identified as somewhat less important. These elements are important for a better representation of the function of urban green spaces or the frequency of road traffic. On the other hand, regarding persons depicted in a virtual environment, we found results that were completely opposite to those of Jaalama et al. (2021), when their respondents stated that they most often paid attention to people, even more often than to buildings. This discrepancy, however, is likely to be caused by the fact that the respondents were presented with a 3D model of the interior of the shopping mall.

One limitation of our user approach to user testing was the fixed order of tasks. This could have introduced a learning effect, as respondents became more familiar with the interface and tasks as they progressed. While we mitigated this by not presenting tasks immediately after one another, future studies could further address this by randomising the task order. Additionally, while we did not explicitly limit or monitor response times, future studies could benefit from incorporating also time-based measures to understand the cognitive load. Finally, to gain a more comprehensive understanding of user experiences, it would be beneficial to combine our current approach with other research methods, both quantitative and qualitative, specifically user logging (Chassin et al. 2022; Hasanzadeh et al. 2023), eye-tracking (Popelka, Dědková 2014; Burian, Popelka, Beitlova 2018), interviews (Häberling, Bär, Hurni 2008), think-aloud protocols or combinations of these methods (Onyimbi, Koeva, Flacke 2018).

The final part of the questionnaire investigated the control conditions. Respondents stated that the 3D models were mostly loaded quickly enough; unsurprisingly, the photorealistic model had a longer loading time because this variant of visualisation contains more objects or raster textures. A key aspect of the tested 3D geovisualisation is interactivity. Lovett et al. (2015) argue that interaction deepens user engagement with geovisualisations. Created interactive geovisualisation is designed to be versatile, functioning seamlessly across various platforms, both personal computers, which were used in this study, and Head Mounted Displays, as well as smartphones. Future research could explore the optimal level of interaction for these specific devices and contexts.

As part of the subjective assessment of work with symbolised 3D models, respondents emphasised the importance of a clear legend, mentioned in the case of 2D maps by Burian, Šťávová (2009). Specifically, respondents mentioned the possibility of looking at the entire model from above with a legend, which could be fixed in a corner (above the 3D model itself) or floating on the horizon of the 3D model. Another functionality that could be used to expand the created 3D geovisualisations is, for example, switching layers of object types and textures (Judge, Harrie 2020; Jaalama et al. 2021). It was stated that this would be especially beneficial for the vegetation layer. This could also reduce the loading time of 3D models. It would also be possible to add control elements, such as a slider for comparing scenes or the possibility of pop-up windows, which are recommendations of Judge, Harrie (2020).

6. Conclusion

This study highlights the strengths and limitations of photorealistic and symbolised 3D geovisualisations in participatory urban planning, with a focus on differences in both objective performance and subjective assessments. Symbolised models demonstrated higher accuracy for objective measures, particularly for experts and men, who found them better suited for tasks requiring clarity and efficiency. These models excel in simplifying complex spatial information, reducing cognitive load, and enabling accurate decision-making. On the contrary, photorealistic models were favoured for their immersive and detailed representation, enhancing spatial understanding and engagement, particularly among laypersons and women. These findings verify a divergence between what users perceive as effective or engaging and their actual task performance. The contrast between subjective satisfaction and objective outcomes underscores the need for a balanced approach in designing geovisualisations. Together, these visualisation types address different but complementary aspects of participatory urban planning, highlighting the importance of aligning tools with the diverse needs and expectations of stakeholders. Furthermore, this research highlights the role of 3D geovisualisations in democratising urban planning by facilitating communication, understanding, and collaboration.

Future research should explore dynamic, customisable geovisualisations and employ complementary methods such as eye-tracking, think-aloud protocols, and interviews to deepen our understanding of user interactions with 3D models. By addressing these considerations, urban planners can better leverage geovisualisations to foster democratic public engagement in shaping sustainable urban futures. Hasanzadeh et al. (2023) mention that the use of 3D geovisualisation in combination with PPGIS tools is a previously unexplored territory and holds great potential for participatory research within cities. Future studies may focus on the practical use of different variants of 3D geovisualisation for data collection or insights from respondents. It might be useful to test what types of geometry are appropriate for placing values in 3D space, also in relation to the scale of the study site. Attention should also be given to the methods in which the collected data can be further analysed and visualised, or which other participatory mapping tools the research could be combined with.

In conclusion, the divergence between subjective preferences and objective performance measures highlights the complexity of designing effective 3D geovisualisations. By acknowledging and addressing these differences, urban planners can leverage the complementary strengths of photorealistic and symbolised models to support more inclusive and effective participatory planning processes. Ultimately, thoughtful visualisation design can empower stakeholders to engage meaningfully in shaping sustainable urban futures.

References

ATELIER PROREGIO S. R. O. (2023): Územní studie Otrokovice: Lokalita za Arboretem, https://www.otrokovice.cz/assets/File.ashx?id_org=11673&id_dokumenty=25233 (2. 12. 2024).
BANDROVA, T., BONCHEV, S. (2013): 3D Maps Scale, Accuracy, Level of Detail. 26th International Cartographic Conference, 25–30 August 2013, Dresden, Germany.
BILJECKI, F., STOTER, J., LEDOUX, H., ZLATANOVA, S., ÇÖLTEKIN, A. (2015): Applications of 3D city models: State of the art review. ISPRS International Journal of Geo-Information, 4, 4, 2842–2889. https://doi.org/10.3390/ijgi4042842
BILLGER, M., THUVANDER, L., WÄSTBERG, B.S. (2017): In search of visualization challenges: The development and implementation of visualization tools for supporting dialogue in urban planning processes. Environment and Planning B: Urban Analytics and City Science, 44, 6, 1012–1035. https://doi.org/10.1177/0265813516657341
BLEISCH, S. (2012): 3D Geovisualization – Definition and Structuresfor the Assessment of Usefulness. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, I-2, 129–134. https://doi.org/10.5194/isprsannals-I-2–129-2012
BRNO CITY CHIEF ARCHITECT'S OFFICE, KAM (2019): 3D MODEL OF BRNO, https://webmaps.kambrno.cz/3d-model_en/ (2. 12. 2024).
Building Act No. 283/2021 Coll. (2021), https://www.zakonyprolidi.cz/cs/2021–283 (10. 12. 2024).
BURIAN, J., POPELKA, S., BEITLOVA, M. (2018): Evaluation of the cartographical quality of urban plans by eye-tracking. ISPRS International Journal of Geo-Information, 192, 7, 1–25. https://doi.org/10.3390/ijgi7050192
BURIAN, J., ŠŤÁVOVÁ, Z. (2009): The difficulties of using urban plans for cartographers and geoinformatists. Geografie, 114, 3, 179–191. https://doi.org/10.37040/geografie2009114030179
CARNEIRO, C. (2008): Communication and visualization of 3-D urban spatial data according to user requirements: case study of Geneva. Proceedings of the XXI ISPRS Congress, XXXVII, 631–636.
CHASSIN, T., INGENSAND, J., CHRISTOPHE, S., TOUYA, G. (2022): Experiencing virtual geographic environment in urban 3D participatory e-planning: A user perspective. Landscape and Urban Planning, December 2021, 224, 104432. https://doi.org/10.1016/j.landurbplan.2022.104432
CZECH OFFICE FOR SURVEYING MAPPING AND CADASTRE (2024): WMS view service – Orthophoto, https://geoportal.cuzk.cz/(S(bowxsndpqogcayvjnsso051q))/Default.aspx?lng=EN&mode=TextMeta&side=wms.verejne&metadataID=CZ-CUZK-WMS-ORTOFOTO-P&metadataXSL=metadata.sluzba&head_tab=sekce-03-gp&menu=3121 (2. 12. 2024).
CZECH STATISTICAL OFFICE (2025): Definitions, https://csu.gov.cz/2_definitions_ (18. 2. 2025).
DENÍK VEŘEJNÉ SPRÁVY (2019): Budoucnost územního plánování leží ve 3D. Nabízí snadnější orientaci i představu o tom, co přinese nová výstavba, https://denik.obce.cz/clanek.asp?id=6785987 (3. 12. 2024).
DENWOOD, T., HUCK, J. J., LINDLEY, S. (2022): Effective PPGIS in spatial decision-making: Reflecting participant priorities by illustrating the implications of their choices. Transactions in GIS, 26, 2, 867–886. https://doi.org/10.1111/tgis.12888
DÖLLNER, J. (2007): Non-photorealistic 3D geovisualization. Multimedia Cartography: Second Edition. Springer Heidelberg, 229–240. https://doi.org/10.1007/978-3-540-36651-5_16
DOULA, A., KAUFMANN, P., GUINEA, A. S., MUHLHAUSER, M. (2022): Effects of the Level of Detail on the Recognition of City Landmarks in Virtual Environments. Proceedings – 2022

IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, VRW 2022, 860–861. https://doi.org/10.1109/VRW55335.2022.00281
DUŠEK, R., MIŘIJOVSKÝ, J. (2009): Visualisation of geospatial data: chaos in the dimensions. Geografie, 114, 3, 169–178. https://doi.org/10.37040/geografie2009114030169
EILOLA, S., JAALAMA, K., KANGASSALO, P., NUMMI, P., STAFFANS, A., FAGERHOLM, N. (2023): 3D visualisations for communicative urban and landscape planning: What systematic mapping of academic literature can tell us of their potential? Landscape and Urban Planning, June 2022, 234, 104716. https://doi.org/10.1016/j.landurbplan.2023.104716
FAGERHOLM, N., RAYMOND, C.M., OLAFSSON, A.S., BROWN, G., RINNE, T., HASANZADEH, K., BROBERG, A., KYTTÄ, M. (2021): A methodological framework for analysis of participatory mapping data in research, planning, and management. International Journal of Geographical Information Science, 9, 35, 1848–1875. https://doi.org/10.1080/13658816.2020.1869747
FILA, M., ŠTAMPACH, R., STACHOŇ, Z. (2024): The role of level of detail in 3D cartographic visualizations. Geografie, 129, 2, 159–185. https://doi.org/10.37040/geografie.2024.007
GARDONY, A.L., HENDEL, D.D., BRUNYÉ, T.T. (2022): Identifying optimal graphical level of detail to support orienting with 3D geo-visualizations. Spatial Cognition and Computation, 22, 1–2, 135–160. https://doi.org/10.1080/13875868.2021.1892696
GATZIDIS, C., BRUJIC-OKRETIC, V., MASTROYANNI, M. (2009): Evaluation of Non-Photorealistic 3D Urban Models for Mobile Device Navigation. April, 18–31. https://doi.org/10.1007/978-3-642-02771-0_20
HÄBERLING, C., BÄR, H., HURNI, L. (2008): Proposed cartographic design principles for 3D maps: A contribution to an extended cartographic theory. Cartographica, 43, 3, 175–188. https://doi.org/10.3138/carto.43.3.175
HASANZADEH, K., FAGERHOLM, N., SKOV-PETERSEN, H., OLAFSSON, A.S. (2023): A methodological framework for analyzing PPGIS data collected in 3D. International Journal of Digital Earth, 1, 16, 3435–3455. https://doi.org/10.1080/17538947.2023.2250739
HAYEK, U.W. (2011): Which is the appropriate 3D visualization type for participatory landscape planning workshops? A portfolio of their effectiveness. Environment and Planning B: Planning and Design, 38, 5, 921–939. https://doi.org/10.1068/b36113
HERBERT, G., CHEN, X. (2015): A comparison of usefulness of 2D and 3D representations of urban planning. Cartography and Geographic Information Science, 42, 1, 22–32. https://doi.org/10.1080/15230406.2014.987694
INSTITUTE OF REGIONAL PLANNING PRAGUE (2024): 3D model of Prague, https://app.iprpraha.cz/apl/app/model3d/ (3. 12. 2024).
ISO (2019): ISO 9241–210. Ergonomics of Human-System Interaction – Part. 210: Human-Centred Design for Interactive Systems, https://www.iso.org/standard/77520.html (3. 12. 2024).
JAALAMA, K., FAGERHOLM, N., JULIN, A., VIRTANEN, J.P., MAKSIMAINEN, M., HYYPPÄ, H. (2021): Sense of presence and sense of place in perceiving a 3D geovisualization for communication in urban planning – Differences introduced by prior familiarity with the place. Landscape and Urban Planning, November 2020, 207. https://doi.org/10.1016/j.landurbplan.2020.103996
JAHNKE, M., KRISP, J.M., KUMKE, H. (2011): How many 3D city models are there? – A typological try. Cartographic Journal, 48, 2, 124–130. https://doi.org/10.1179/1743277411Y.0000000010
JUDGE, S., HARRIE, L. (2020): Visualizing a Possible Future: Map Guidelines for a 3D Detailed Development Plan. Journal of Geovisualization and Spatial Analysis, 4, 1. https://doi.org/10.1007/s41651-020-00049-4

JUŘÍK, V., HERMAN, L., ŠAŠINKA, C., STACHOŇ, Z., CHMELÍK, J., STRNADOVÁ, A., KUBÍČEK, P. (2018): Behavior Analysis in Virtual Geovisualizations: Towards Ecological Validity. 7th International Conference on Cartography and GIS, June, 1 and 2, 518–527.

KIBRIA, M. S., ZLATANOVA, S., ITARD, L., VAN DORST, M. (2009): GeoVEs as tools to communicate in urban projects: Requirements for functionality and visualization. Lecture Notes in Geoinformation and Cartography, 379–395. https://doi.org/10.1007/978-3-540-87395-2_24

KONEČNÝ, M. (2011): Cartography: Challenges and potential in the virtual geographic environments era. Annals of GIS, 17, 3, 135–146. https://doi.org/10.1080/19475683.2011.602027

LEE, J., YANG, B. (2019): Developing an optimized texture mapping for photorealistic 3D buildings. Transactions in GIS, 23, 1, 1–21. https://doi.org/10.1111/tgis.12494

LEVEND, S., FISCHER, THOMAS, B. (2023): Participatory Urban planning – introducing and testing a 2D/3D visualization and AHP framework. Megaron, 18, 2, 184–201. https://doi.org/10.14744/megaron.2023.97947

LOKKA, I.E., ÇÖLTEKIN, A. (2019): Toward optimizing the design of virtual environments for route learning: empirically assessing the effects of changing levels of realism on memory. International Journal of Digital Earth, 12, 2, 137–155. https://doi.org/10.1080/17538947.2017.1349842

LOVETT, A., APPLETON, K., WARREN-KRETZSCHMAR, B., VON HAAREN, C. (2015): Using 3D visualization methods in landscape planning: An evaluation of options and practical issues. Landscape and Urban Planning, 142, 85–94. https://doi.org/10.1016/j.landurbplan.2015.02.021

MACEACHREN, A.M., KRAAK, M.-J. (2001): Research Challenges in Geovisualization. Cartography and Geographic Information Science, 28, 1, 3–12. https://doi.org/10.1559/152304001782173970

MAGISTRÁT MĚSTA BRNA ODDĚLENÍ GIS (2024a): Územní plán města Brna, https://gis.brno.cz/mapa/upmb/?c=-597822.5%3A-1159214.3&z=4&lb=zm-brno-seda-all&ly=uln%2Cup18&lbo=1&lyo= (2. 12. 2024).

MAGISTRÁT MĚSTA BRNA ODDĚLENÍ GIS (2024b): Připravovaný Územní plán města Brna – Návrh pro veřejné projednání, https://gis.brno.cz/mapa/upmb-navrh/?c=-597822.5%3A-1159214.3&z=4&lb=zm-brno-seda-all&ly=uln%2Cv21&lbo=1&lyo= (2. 12. 2024).

MARSHALL, S., FARNDON, D., HUDSON-SMITH, A., KOURNIOTIS, A., KARADIMITRIOU, N. (2024): Urban Design and Planning Participation in the Digital Age: Lessons from an Experimental Online Platform. Smart Cities, 7, 1, 615–632. https://doi.org/10.3390/smartcities7010025

ONYIMBI, J.R., KOEVA, M., FLACKE, J. (2018): Public participation using 3D web-based city models: Opportunities for e-participation in Kisumu, Kenya. ISPRS International Journal of Geo-Information, 7, 12, 1–20. https://doi.org/10.3390/ijgi7120454

OPEN GEOSPATIAL CONSORTIUM (2024): City Geography Markup Language (CityGML) Encoding Standard, https://www.ogc.org/standard/citygml/ (2. 12. 2024).

PLAČKOVÁ, B. (2025): Research on the implementation of interactive 3D models in the field of urban and spatial planning (Průzkum implementace interaktivních 3D modelů do oblasti územního a prostorového plánování). figshare. https://doi.org/10.6084/m9.figshare.28436378.v1

POPELKA, S., DĚDKOVÁ, P. (2014): Extinct village 3D visualization and its evaluation with eye-movement recording. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), PART 1, 8579 LNCS, 786–795. https://doi.org/10.1007/978-3-319-09144-0_54

RAUTENBACH, V., COETZEE, S., ÇÖLTEKIN, A. (2014): Towards evaluating the map literacy of planners in 2D maps and 3D models in South Africa. AfricaGEO 2014 Conference Proceedings, 1–12.

STATUTÁRNÍ MĚSTO BRNO (2022): Vrstevnice 2019 / Contours 2019, Magistrát města Brna – Otevřená data, https://data.brno.cz/datasets/46cddb79dde54338a3aaa56b6c4287f1_0/explore (2. 12. 2024).

VOŽENÍLEK, V. (2005): Cartography for GIS. Univerzita Palackého v Olomouci, Olomouc.

ACKNOWLEDGEMENTS

This work was supported by the Masaryk University, grant Dynamics of the natural and social environment in geographical perspective number MUNI/A/1648/2024. The authors would like to thank the Brno City Municipality for the data provided for the creation of the 3D geovisualisations. Finally, we would like to thank the participants for their time and efforts.

ORCID

LUKÁŠ HERMAN
https://orcid.org/0000-0003-4106-2569

JAN MIKOLÁŠ
https://orcid.org/0009-0009-8432-6676

JAKUB KURA
https://orcid.org/0000-0003-0773-7497

DAJANA SNOPKOVÁ
https://orcid.org/0000-0002-0568-6211