# The role of level of detail in 3D cartographic visualizations

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ABSTRACT Investigating the geometric level of detail and the visual level of realism, the study examines the effect of level of detail on users' perceptions of 3D visualizations in an experiment that employs textures to render building facades. The effects of level of detail and level of realism are explored by testing users with four variations of the same virtual environment – MixedVE level of detail 1, RealisticVE level of detail 1, MixedVE level of detail 2, and RealisticVE level of detail 2. The experiment is a between-subject design involving eighty participants and two real-time tasks and measures both quantitative and qualitative data. The results of the experiment indicate that the participants in level of detail 2, with no time limit applied to the task, identified religious buildings more easily than in level of detail 1. In the second task, with a time limit applied, the participants discovered pharmacies more easily in the MixedVE than in the RealisticVE.

KEY WORDS 3D cartographic visualization – virtual environment – level of detail – level of realism – user testing – between-subject

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## 1. Introduction

Over time, terms such as 3D visualization, virtual environment, and virtual reality have been appearing increasingly in the everyday speech of scientists, computer game enthusiasts, and the public generally, suggesting that the technology for 3D imaging is becoming more widely used in society. 3D technologies can be found in many fields, for example, urban planning (Chassin et al. 2022), city modeling (Biljecki et al. 2016), digital twin production (Herman et al. 2021), creation of building energy models (Johari et al. 2022), emergency management planning (Tashakkori, Rajabifard, Kalantari 2015), and route navigation (Shi et al. 2022). However, 3D visualizations are not able to replace 2D visualizations in every field. For example, the increased cognitive load required by interpreting 3D visualizations is a significant drawback; controlling the volume of information is, therefore, a method to address this problem (Lokka et al. 2018).

Recent times have seen remarkable progress in computer technology, which has enabled users to explore virtual environments and traverse endless virtual spaces. Virtual environments that simulate the real world, especially extensive 3D models of cities, are becoming more complex in order to meet the increasing demand for virtual environments that contain finer detail. The creation of 3D models from a variety of visual aspects and subsequent testing on ordinary users is, therefore, vital research. However, extensive 3D models of cities suffer from the limitations dictated by the fundamental requirements for high computing performance and processing of significant volumes of spatial data. Regarding the latter, the OpenStreetMap database (OpenStreetMap 2023) is an example of a freely available and comprehensive dataset to which volunteers (mappers) from around the world add their contributions.

With a wide range of available visualization options, it is possible to simulate large areas of the natural world in a virtual environment and set up customized experiments to test, for example, the exploration of the visual aspects of an entire 3D city model. In GIScience, parameters such as level of detail, which describes geometric detail, and level of realism, which describes visual appearance, are applied to render the appearance of 3D objects. Researchers are seeking 3D cartographic visualization methods that do not entail a high cognitive load yet allow users to orient themselves sufficiently within the 3D environment.

As 3D visualization technologies become more integrated into society, understanding how levels of detail and levels of realism in 3D visualizations affect user perception and interaction becomes crucial. The current study's main aim is to determine the effect of the level of detail on the user's perception of a 3D visualization by investigating which level of detail in a virtual environment is the most suitable for user work. We, therefore, propose the following research question: Do the level of detail and level of realism affect the perception of 3D visualizations?

In addition to the geometric level of detail, the study investigates the visual level of realism, i.e., the size of the textures applied to building facades, to determine any effects on users' perceptions of 3D visualizations.

## 2. Related works

Since the terms level of detail and level of realism are essential to this area of research, the definitions are provided here. The term level of detail includes the degree of generalization and the complexity or number of elements in a 3D model. level of detail concepts are described differently by various authors (Abualdenien, Borrmann 2022; Sun, Zhou, Hou 2020; Johari et al. 2022); for example, Building Information Modeling (Eastman et al. 2011) and CityGML (OGC 2023). Although these concepts are not firmly anchored in a formal nomenclature, all are generally accepted as valid. The concept of level of detail is broadly tied to an object's presence, geometric complexity, and parts (Biljecki, Ledoux, Stoter 2017, Peters et al. 2016).

Samsonov (2022) applies a level of detail at a small scale; most studies, however, use a level of detail in large-scale visualizations of cities with 3D buildings. At the scale of a building, 3D models are often conceptualized with the Building Information Modelling framework. At the scale of a city, CityGML describes urban objects with a range of levels of detail (Yu et al. 2022). In the current study, we selected a level of detail concept CityGML specification (OGC 2023) and worked with level of detail 1 and level of detail 2.

The user tests designed for the current study work with the virtual environment's level of realism in the size and number of textures applied to buildings rendered in the scene. Many authors have investigated the effect of level of realism on people's perceptions of cartographic visualizations, and their conclusions lack consistency. Some authors state that 3D visualizations with a higher level of realism are more acceptable to users for memorization and interpretation (Loomis, Blascovich, Beall 1999; Dennehy, Nesbitt, Sumey 1994). Others conclude that a higher level of realism has a negative impact since it places a certain cognitive load on the user (MacEachren 2004, Cowan 2001, Shepherd 2008, Seipel 2013). Bertin (1983) states that simplification is a mandatory part of communication. Smallman and St. John (2005) note that naive realism can mistakenly convince users that visualizations with higher realism are accurately transformed into mental representations, whereas in reality, the contrary is observed. Since their creation, visualizations for virtual environments with different levels of detail have been empirically tested for specific purposes and to examine the effects on groups of users. Many studies have investigated this area, but the researchers' conclusions often diverge.

In urban planning and architecture, Chassin et al. (2022) note that the level of detail 1 and the more straightforward level of detail 2 produce better results than the complex level of detail 2. Their results indicate that a higher level of abstraction or salient elements significantly decreases the time needed to complete the tasks of the experiments. A user study by Doula et al. (2022), however, proves that a higher level of detail leads to improved landmark identification. Similarly, Kibria et all (2009) conclude that increases in realism, level of detail, and dimensionality increase the user's linear perception of understanding the design of an object in the virtual environment.

In the area of emergency management, many papers explore the use of 3D for indoor mapping. Sun, Zhou, Hou (2020) describe that even the use of level of detail 4 is insufficient for emergency management if inner obstacles (e.g., furniture) are not modeled. Tashakkori, Rajabifard, Kalantari (2015) note that the use of a model that does not exhibit unnecessary complexity improves situational awareness, optimizes route finding, and consequently decreases indoor route travel times.

Biljecki et al. (2016) test the use of 3D building models for spatial analysis, and their results suggest that the level of detail 1 with a specific geometric reference may yield more accurate results than the level of detail 2 models. Level of detail 1 is recommended for the assessment of traffic noise propagation (Ranjbar, Gharangozlou, Nejad 2012) and line of sight analysis (Yaagoubi et al. 2015). Level of detail 2 can be applied to a range of purposes; for example, the determination of usable building space (Boeters et al. 2015) or the improvement of satellite positioning (Wang, Groves, Ziebart 2013).

As discussed in other studies, the context in which the study is performed is an important factor. In the current study, testing was controlled on three levels: stimuli, task, and the user (Martin 2008, Çöltekin 2015, Çöltekin, Lokka, Zahner 2016). A representative sample of participants who possess the necessary skills and expertise is also crucial in user testing. Participants can be selected and tested according to predetermined parameters relevant to the study; for example, age (Lokka, Çöltekin 2017; Jokisch, Bartoschek, Schwering 2011), gender (Liao, Dong 2017), expertise (Popelka, Brychtová 2013; Hildebrandt, Timm 2014; Shi et al. 2022), or spatial or visual ability (Kubíček et al. 2017, Stachoň et al. 2018).

In evaluating any empirical results, the type of 3D visualization is significant from the perspective of the tested stimuli. Studies in this field discuss a range of stimulus variables: level of realism (Fosse, Centeno, Sluter 2009; Zanola, Fabrikant, Çöltekin 2009; Stachoň et al. 2018), level of detail (Bandrova, Bonchev 2013; Shi et al. 2022), visualization dimensionality, such as real-3D or pseudo-3D (Seipel 2013, Torres et al. 2013, Špriňarová et al. 2015, Kubíček et al. 2017), control devices (Špriňarová et al. 2015), user behavior (Ugwitz et al. 2019), and level of navigational interactivity, such as static or interactive 3D maps (Kubíček et al. 2017). Stimulus variables are generally the first components to be examined. Stimuli are widely variable and can be set up according to the research design, for example, level of detail, level of realism, or scene complexity. The tasks then assigned to users are designed according to the stimuli and the specific goals of the testing scenario.

Shi et al. (2022) studied the effect of level of detail on driver behavior in a driving simulation. The simulation replicates a real location and contains four levels of detail: level of detail 0 (only the road is rendered) to level of detail 3 (where buildings display natural textures). In all four simulations, the participants drive a virtual vehicle. The results of the study show that the effect of the level of detail is not significant; the geometric features of the route and environmental elements constrain driving behavior much more than the level of detail. Gardony, Hendel, Brunyé (2022) demonstrate that a moderate (rather than maximum) level of detail is sufficient for spatial orientation.

Lokka et al. (2018) study user behavior and memorization of a path and 3D objects in a virtual environment. The authors designed three virtual environments: (i) a Realistic virtual environment with building facade textures, (ii) an Abstract virtual environment with no building facade textures, and (iii) a combination of realistic and abstract environments (Mixed virtual environment). In a Mixed virtual environment, certain landmark buildings are rendered with textures. The experiment involved 81 participants, divided into two groups according to age: 42 participants in the younger group (average age 27 years) and 39 in the older group (average age 70 years). Both groups solved tasks in two stages, traveling the route on two occasions, one week apart. The results show that both participant groups orientated themselves more quickly in the Mixed virtual environment. Before the experiment, the participants had indicated preferences for the Realistic virtual environment. After testing, participants in both groups indicated their preference for the Mixed virtual environment.

The current study's main aim is to determine which of the proposed virtual environments with different levels of detail is the most suitable for users to work with. The study partially follows up on the research mentioned above by Lokka et al. (2018) and Shi et al. (2022), with the adjustment and addition of a few variables (virtual environment types/designs, control, tasks) and omission of others (age, two stages of recall). Shi et al. (2022) test four different levels of detail but only one level of realism (texture is used only for level of detail 3 visualizations). Lokka et al. (2018) test three different levels of realism but only one level of detail.

The current study differs from the related works in the field by investigating the possible effect on users in environments that apply different combinations of level of detail and level of realism. To maintain a manageable number of explorable environments, we test only combinations of levels of detail 1 and 2 and levels of realism Mixed and Realistic. In the study by Shi et al. (2022), the Abstract level of realism produced the weakest results, and level of detail 0 and level of detail 3 were used less often than level of detail 1 and level of detail 2.

## 3. Methodology

### *3.1. Methods*

The experiment's independent variable was visualization type (two variants of the level of detail 1: Realistic and Mixed; two variants of the level of detail 2: Realistic and Mixed). The experiment's measured dependent variables were: (i) the number of religious buildings that a user correctly identified during the first real-time task in the virtual environment, (ii) the number of pharmacies that a user correctly identified during the second real-time task in the virtual environment, (iii) the time that a user spent in the virtual environment, and (iv) the distance that a user walked in the virtual environment.

Data collection in research generally applies several methods simultaneously to improve an experiment's efficiency, effectiveness, reliability, validity, statistical significance, and results (Roth 2016). According to Štěrba et al. (2015), the use of only qualitative or quantitative research methods is insufficient, and a combination of methods is much more effective in obtaining reliable results. The testing methods applied in the current study include a structured questionnaire, real-time tasks (tasks performed in the virtual environment in real-time), and measurement of quantitative and qualitative data during real-time tasks. Participants were tested using DesktopVR equipment (24″ LCD monitor with 1920 × 1080 resolution @ 60 Hz).

### *3.2. Terminology*

In our study, we use the term level of detail as defined in the CityGML specification (OGC 2023). The term level of realism refers to a scale of visual appearance and photorealism, i.e., a high level of realism. The number of realistic textures applied in the experiment determines its level of realism (Zanola, Fabrikant, Çöltekin 2009). To create the virtual environments for the experiment, we took inspiration from Lokka et al. (2018), who apply three levels of realism (Abstract × Realistic × Mixed):

- Abstract/Abstract virtual environment – Virtual environment rendered in grayscale, without textures (not used in the current study).
- Realistic/Realistic virtual environment – Fully textured virtual environment (used in the current study).
- Mixed/Mixed virtual environment – Virtual environment combining the previous two styles (realistic and abstract). Most elements are rendered in grayscale, but buildings at critical positions and the road network are textured (used in the current study).

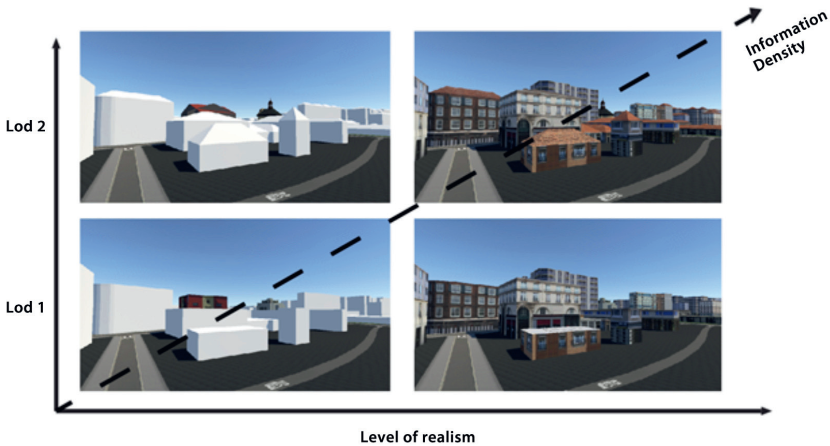


**Fig. 1** – The relationship between level of detail (Lod), level of realism, and information density. Source: Stachoň, Kubíček, Herman 2020.

The combination of level of detail and level of realism forms a close relationship with information density (Fig. 1).

For improved readability and comprehension, we introduce several abbreviations for the virtual environment and use them throughout the text:

- LoD1 – level of detail 1 as defined in the CityGML specification (OGC 2023). Blocks model comprising prismatic buildings with flat roofs.
- LoD2 – level of detail 2 as defined in the CityGML specification (OGC 2023). Buildings with differentiated roof structures.
- MixedVE – Landmarks/Buildings (e.g., post offices, police stations, churches, and other major objects) that are important for orientation are textured; other buildings in the environment are rendered white.
- RealisticVE – All buildings in the virtual environment are textured.
- 1M = virtual environment with a level of detail LoD1 (geometric detail) and level of realism MixedVE (visual detail).
- 1R = virtual environment with a level of detail LoD1 (geometric detail) and level of realism RealisticVE (visual detail).
- 2M = virtual environment with a level of detail LoD2 (geometric detail) and level of realism MixedVE (visual detail).
- 2R = virtual environment with a level of detail LoD2 (geometric detail) and level of realism RealisticVE (visual detail).

## 4. Experiment

This section outlines the study's research hypotheses, virtual environment, tasks, participants, and experimental design for evaluating user tasks.

### *4.1. Hypotheses*

The experiment compared effectiveness (number of correct answers) and efficiency (time elapsed, distance traveled) (ISO/TS 20282–2 2013). Each hypothesis applies a comparative formula (<, >) in conjunction with the estimated, more valuable results for the virtual environment (LoD1, LoD2 or RealisticVE, MixedVE) concerning the evaluated criteria (average number of the identified religious buildings, average number of pharmacies found, etc.). Each hypothesis specifies its main evaluation criterion.

Applying this approach, the hypotheses and evaluation criteria for the experimental tasks are as follows:

a) First task: Hypothesis 1 (LoD1 > LoD2) In the first task, the participants identify, on average, more religious buildings in LoD1 than LoD2 by recognizing the characteristic roof structures of these buildings and possibly also the shadows of these buildings cast onto other buildings (Lokka et al. 2018). The criterion for confirming/rejecting the hypothesis is the average number of religious buildings identified.

b) Second task: Hypothesis 2 (MixedVE > RealisticVE) The participants discover, on average, more pharmacies in the MixedVE than the RealisticVE, the cognitive load being more acceptable and the level of realism being sufficient for identification. In addition, LoD1 contains no hipped roofs, which cast shadows onto other buildings (Lokka et al. 2018, MacEachren 2004, Cowan 2001, Shepherd 2008, Seipel 2013). The criterion for confirming/rejecting the hypothesis is the average number of pharmacies found.

### *4.2. Virtual environment (stimuli)*

The virtual environment represents the layout of Bruntál, a small town in Czechia, but not all elements have been preserved according to reality. Some original elements have been omitted from the virtual environment or altered in layout, shape, or topology. Visually, the final appearance of the virtual environment does not correspond to the real town of Bruntál. Only the positions and layouts of individual buildings were carried over. Four visually distinct variants of the virtual environment (2 × 2) were created for user testing (Fig. 2):

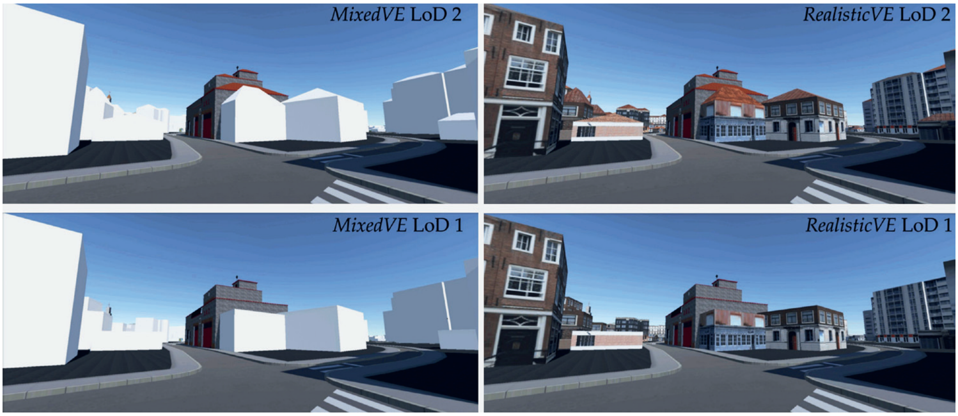


**Fig. 2** – Sample of four variants of the virtual environment with different levels of detail: RealisticVE LoD2 (2R), MixedVE LoD2 (2M), RealisticVE LoD1 (1R) and MixedVE LoD1 (1M) Source: authors.

- RealisticVE LoD1 (1R)
- RealisticVE LoD2 (2R)
- MixedVE LoD1 (1M)
- MixedVE LoD2 (2M)

The 1R virtual environment was visualized with LoD1 buildings with complete facade textures. The 1M environment consists of LoD1 buildings, with facade textures only in critical locations in the virtual environment or areas (e.g., intersections) where decisions are required by the user and represent a meaningful aim (e.g., church, pharmacy). The other two environments were created with LoD2 buildings, with the same differences as in the previous case.

*4.3. Data for creating the stimuli*

OpenStreetMap database (OpenStreetMap 2023) is a source of open data and a useful tool that has become synonymous with volunteer mapping. In addition to spatial analysis, the OpenStreetMap database has also been used for humanitarian mapping activities (Herfort et al. 2021, Štampach et al. 2021), navigational aids (Muñoz-Bañón et al. 2022), and other purposes.

A virtual environment was created for the current study using the OpenStreetMap database, which contains visualizations of buildings, roads, watercourses, and other urban areas. Being open source, covering most of the world, and containing sufficient attribute information to extrude structures, the OpenStreetMap database is highly suitable for virtual environment configurations. The 3D Warehouse web portal (3D Warehouse 2020) is another valuable database where mainly themed structures (e.g., churches, pharmacies, fountains, plague columns) were sourced for the virtual environment. The Asset Store library (Unity Asset Store 2020) was also implemented in Unity software to create certain objects and effects.

### *4.4. Software and creation of the stimuli*

A trial version of the CityEngine 2019.0 software was used to create the virtual environment. Building layouts were first downloaded from the OpenStreetMap portal (OpenStreetMap 2023) and then used to generate individual 3D models. The building textures originated from structures found in the Swiss city of Zurich and were generated automatically from the CityEngine software. Characterized by a mountainous environment, the Czech town of Bruntál is a suitable equivalent to Zurich and was therefore selected for the virtual environment. Rivers and roads were similarly created from OpenStreetMap in CityEngine. Buildings with LoD1 had flat roofs and buildings with LoD2 had either hip or gable roofs. The 3D models of buildings, roads, rivers, and routes created for users were then exported in FBX format and imported into Unity 2018.2.0f2 software.

The virtual environment provides users with several options to control movement. The virtual camera's view and walking direction can be controlled with a computer mouse. Walking can also be controlled with the directional arrows or the WASD keys on a computer keyboard. The virtual camera's view height is 1.8 m above the ground.

### *4.5. Real-time tasks*

Users completed real-time tasks directly in the virtual environment. The tasks designed for testing with users explore a range of objectives; for example, wayfinding (Giannopoulos et al. 2014), finding an object (Ugwitz 2022), identifying an object in a specific location (Herman, Kvarda, Stachoň 2018), exploration (Edler et al. 2018), traveling a given route – following a trail (Málek 2017).

Two task types were created for testing:

1. Identify religious structures in a specific location (identify an object).
2. In two minutes, find as many pharmacies as possible in the city's defined area (find an object).

The users received instructions for completing the real-time tasks directly in the virtual environment; the instructions were displayed on the computer screen for ten seconds before the task commenced.

### *4.6. Measurement of quantitative and qualitative data for real-time tasks*

Quantitative parameters and qualitative data were measured and recorded as each real-time task was completed. The quantitative data consisted of the number of correctly identified buildings, the time required to complete the task (including displayed instructions), the distance walked, the number of stops, and the duration of stops. The qualitative data consisted of the user's coordinates as they passed through the virtual environment and the locations where the user stopped.

### *4.7. Participants*

Eighty-two participants were tested in an experiment with a between-subject design; two participants were excluded from the results because they could not adequately control the first-person avatar. The remaining 80 participants were divided into four groups of 20 and allocated to the proposed virtual environments. Each group comprised 6–8 females and 12–14 males. The participants were approached via social networks and underwent the tests voluntarily. Participants could withdraw from the experiment at any time without giving a reason. None of the participants had any experience in the town of Bruntál, which the virtual environment was modeled on. The questions in the experiment apply a Likert scale: 1 represents the lowest value (1 = low experience), and 5 represents the highest (most) value (5 = high experience).

Each group contained a mix of all age categories. The average age of participants was 28 years across all groups: 31 years in group 1M, 27 years in group 1R, 29 years

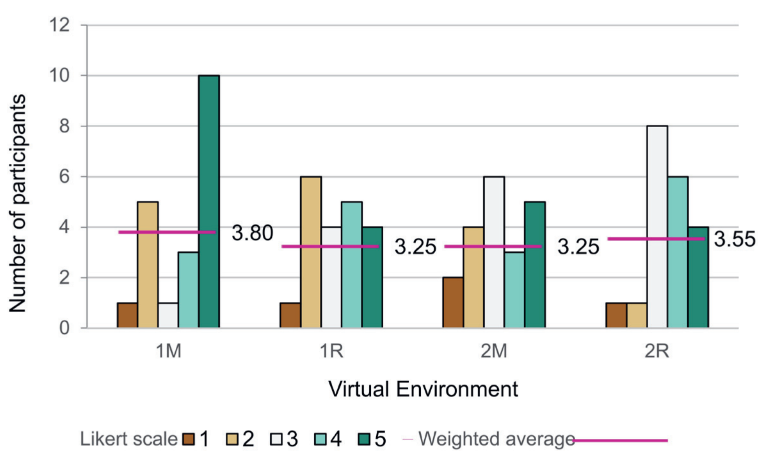


**Fig. 3** – Participants' experience with maps. Source: authors.

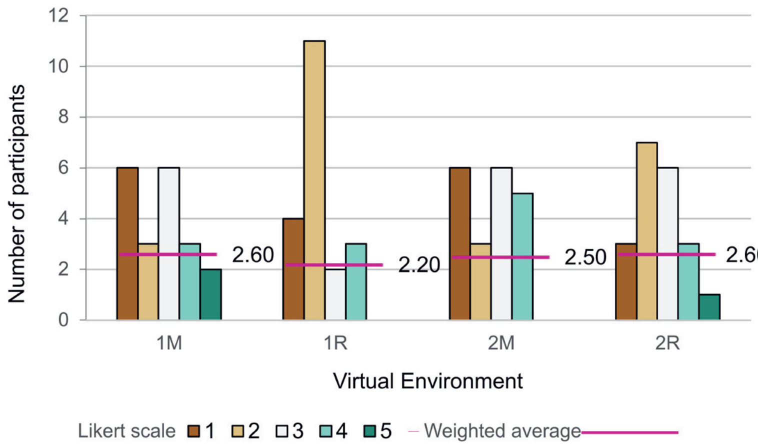


**Fig. 4** – Participants' experience with 3D visualizations. Source: authors.

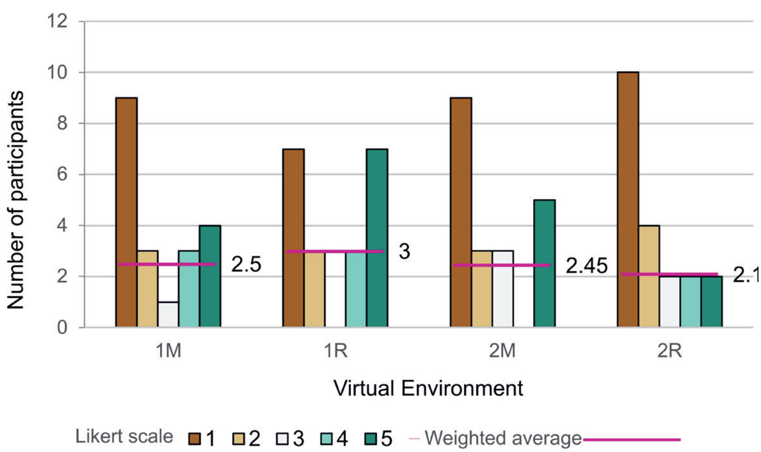


**Fig. 5** – Participants' experience in playing computer games. Source: authors.

in group 2M, and 26 years in group 2R. In experience with using maps, the participants of all four groups indicated weighted average values of approximately 3.25 (1R and 2M) to 3.80 (1M, Fig. 3). In experience with 3D projections, the weighted averages of the number of participants ranged from 2.20 (1R) to 2.60 (1M and 2R, Fig. 4). Finally, in experience with role-playing computer games, the weighted average of the number of participants ranged from 2.1 (2R) to 3.00 (1R, Fig. 5).

### *4.8. Experimental design*

The experiment comprised an introductory stage, a structured questionnaire, instructions for working in the virtual environment, a testing stage, and the final assessment stage (Fig. 6). Completion of all five stages required around 60 minutes, on average.

The introductory stage introduced and acquainted participants with the experiment and the planned course of testing in individual stages. The next stage was a structured questionnaire that obtained basic information about the participant (gender, age, experience with maps, 3D environments, and computer games). The first testing stage began with real-time tasks, instructions, and learning examples in the virtual environment to determine the world's edge, compare the heights of objects, and establish colors. The second testing stage followed with two real-time tasks in one of the virtual environments.

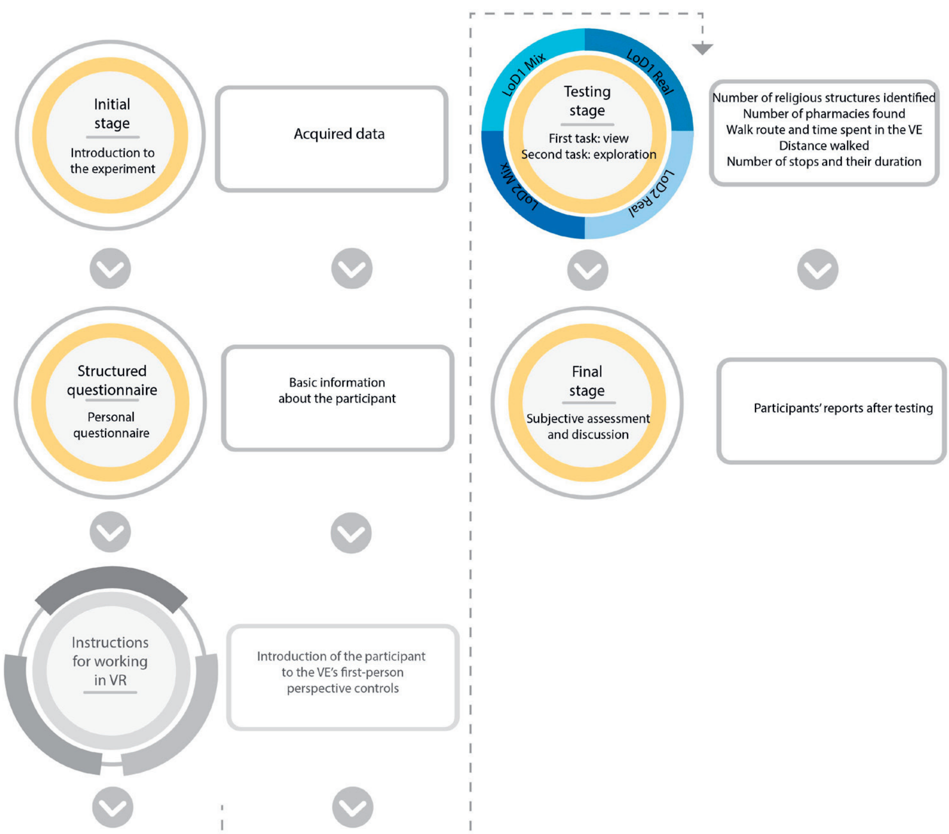


**Fig. 6** – Chronological structure of user testing. Source: authors.

The first task required the participants to identify religious buildings while they viewed from a predetermined location and to record the total number of these objects (participants were not able to move about in the environment). The second task required participants to find pharmacies while they explored confined areas of the town (participants were able to move about in the environment). As the participants walked around and completed the second task, their coordinates were recorded in half-second intervals in a text file. This file provided the data for drawing the participant's walk route (qualitative information) and calculating the total distance walked, the time spent in the virtual environment, and the number and duration of the participant's every stop (quantitative data). In the final stage, the participant rated the task's difficulty on a scale of 1 (easiest) to 5 (most difficult).

## 5. Results

This section discusses the results obtained from the experiment. Statistica analytics software was employed for the statistical analysis and evaluation of the collected data and to create box plots and correlation diagrams for the results. Before each statistical test, the normal distribution of the data was verified with a histogram and the Shapiro–Wilk test.

The analysis examined the directly measured data and the data calculated indirectly from the participants' behaviors (distance walked, time spent in the virtual environment, number and duration of all stops). The analysis showed the degree of correlation with the data for buildings identified/discovered. The statistical investigation method (test) depended on the nature of the data.

### *5.1. First task: identifying religious buildings*

The results for the number of religious buildings identified range from 3.45 (1M) to 4.75 (2R), indicating a difference between each virtual environment of one identified building. The average number of buildings identified was 4.25 in 1R and 4.4 in 2M.

Over half of the participants in 2R (16) and 2M (11) identified all five of the religious structures. In 1M, 2R, and 2M, one extreme value exceeded twice the standard deviation range, where the participant identified significantly fewer religious buildings. The median values were the same in 2M and 2R (5), and the lowest values occurred in 1R (4.25) and 1M (3.5). At a level of significance $\alpha = 0.05$, the F-test showed a statistically significant difference between the variances of the values belonging to the given virtual environment ($p = 0.0003 < \alpha$, Fig. 7).

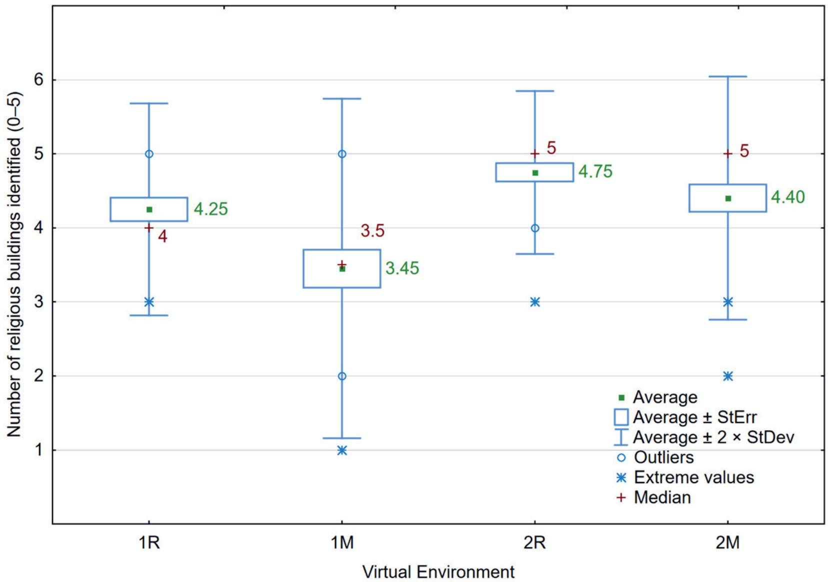


**Fig. 7** – Frequencies, averages (green numbers), and medians (red numbers) of the number of identified religious buildings according to virtual environment Source: authors.

The box plot below indicates that the participants discovered, on average, more religious buildings in the virtual environments that used LoD2 than in the virtual environments that used LoD1 (Fig. 8).

The analysis also examined the relationship between the number of identified religious buildings and the participants' subjective assessments (1 – easiest, 5 – most difficult) of the virtual environments. A negative correlation coefficient was found for the virtual environments with LoD1 and LoD2, indicating an indirect dependence (Fig. 9). Thus, the more religious buildings the participants identified, the more they rated the task as requiring less effort. The virtual environment with LoD1 indicated the most intense indirect relationship ($r = -0.2439$); the correlation coefficient value is closest to −1 and verifies the $p$-value ($p = 0.1294 > \alpha$), which does not reach the critical range of values. Dependence is, therefore, statistically insignificant. The virtual environment with LoD2 indicates an indirect relationship ($r = -0.1383$); the correlation coefficient value verifies the $p$-value ($p = 0.3947 > \alpha$), which does not reach the critical range of values. Dependence is, therefore, statistically insignificant.

Before the statistical analysis, the overdispersion of the data was verified as a variance-to-mean ratio. The result did not exceed the value of 1, therefore a Poisson GLM was applied. A comparison of the LoD1 and LoD2 results using a Poisson GLM (Table 1) shows a statistically insignificant difference at the

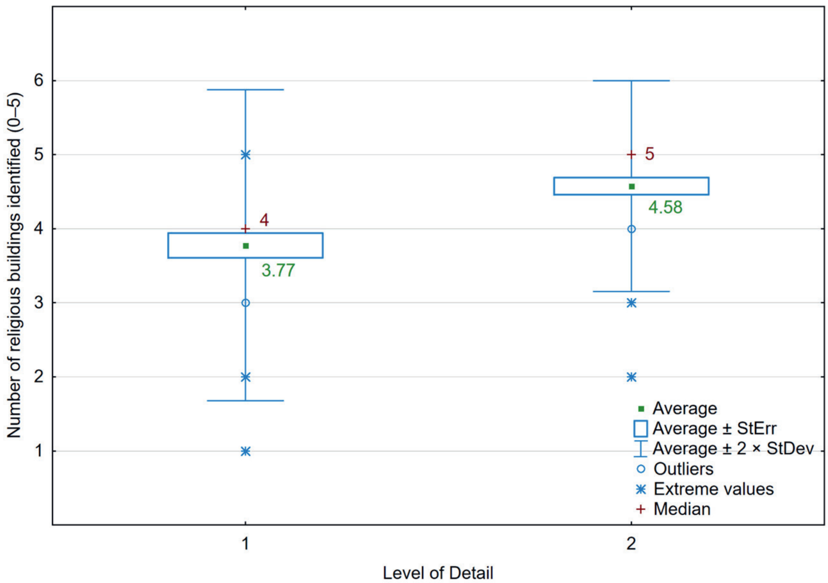


**Fig. 8** – Frequencies, averages (green numbers), and medians (red numbers) of the number of identified religious buildings according to LoD1 and LoD2. Source: authors.

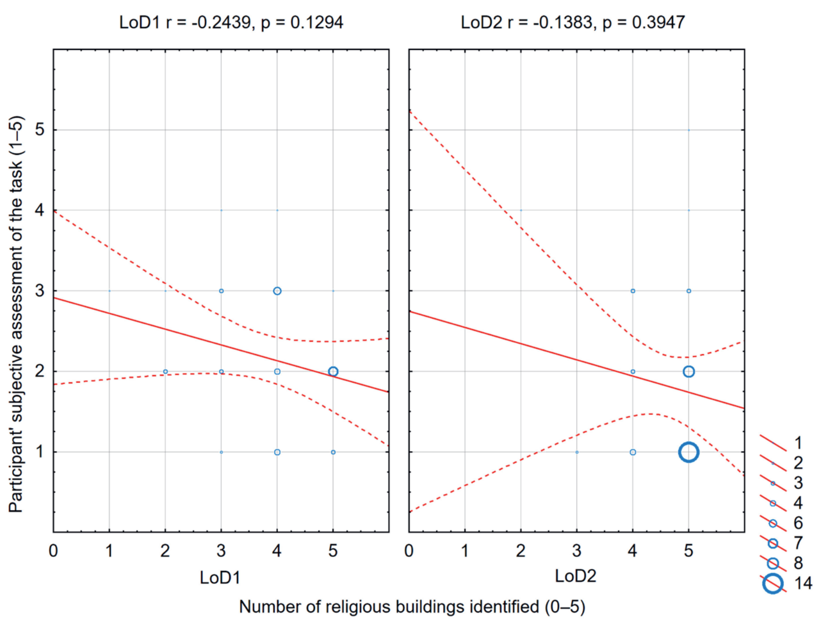


**Fig. 9** – Correlation diagrams of the number of identified religious buildings (0–5) and the participants' subjective assessments (1 – easiest, 5 – most difficult) according to the level of detail. Source: authors.

**Table 1** – Statistical summary of the number of identified religious buildings in the virtual environments

| Dependent variable: The number of religious buildings: | Poisson Generalized Linear Model Independent (grouping) variable: virtual environment (LoD1 × LoD2) Coefficients: | | | |
|---|---|---|---|---|
| | Estimate Std. | Error | Z-value | Pr(>\|z\|) |
| LoD1 (Intercept) | 1.32840 | 0.08138 | 16.324 | <2e-16 |
| LoD2 | 0.19221 | 0.10994 | 1.748 | 0.0804 |

significance level $\alpha = 0.05$, where the *p*-value falls outside the limit for α in the critical range of values ($p = 0.0804 < \alpha$).

The results for the first task indicate that the participants discovered, on average, more religious buildings in the virtual environment with LoD2 than in the virtual environment with LoD1, but the differences between LoD2 and LoD1 are statistically insignificant. In the responses to the supplementary question concerning the strategy the participants applied to find the religious buildings, the most frequently reported keywords are *cross*, *symbol*, *chalice*, *church*, *religious*, and often, *tower* or *roof*.

### *5.2. Second task: finding pharmacies*

The results for the average numbers of pharmacies discovered in two minutes are 2.8 (2R), 3.1 (1R), 3.35 (1M), and 3.6 (2M, Fig. 10). The range of the highest and lowest mean indicates a difference between 2R and 2M of approximately one discovered pharmacy. The median values of discovered pharmacies are the same for 1R and 2R (3) and higher for 1M and 2M (4). Extreme values in the number of discovered pharmacies occurred in 1R and 2R (one pharmacy found).

The discovery of all four pharmacies (Fig. 10) occurred most often in 2M (13 out of 20 participants), followed by 1M (11 out of 20 participants), 1R (8 out of 20 participants), and 2R (6 out of 20 participants). At the $\alpha = 0.05$ significance level, an F-test reveals a statistically significant difference between the variances of individual virtual environments in the number of discovered pharmacies ($p = 0.0359 < \alpha$).

The box plot below indicates that the participants discovered, on average, more pharmacies in the MixedVE than in the RealisticVE (Fig. 11).

An indirect relationship in all four virtual environments exists between the number of discovered pharmacies and the participants' subjective assessments (1 – easiest, 5 – most difficult); all coefficients are negative. The more pharmacies the participants found, the more they rated the task as straightforward. The most

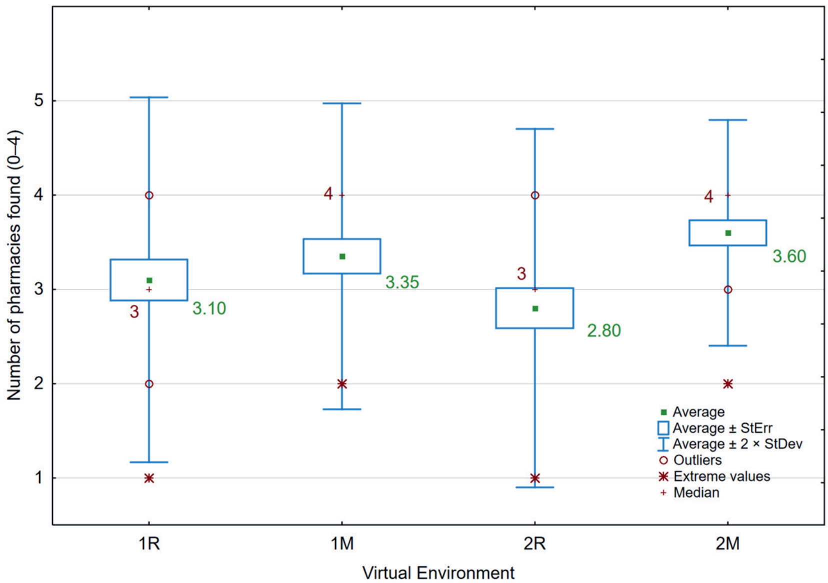


**Fig. 10** – Frequencies, averages (green numbers), and medians (red numbers) of the number of discovered pharmacies according to virtual environment. Source: authors.

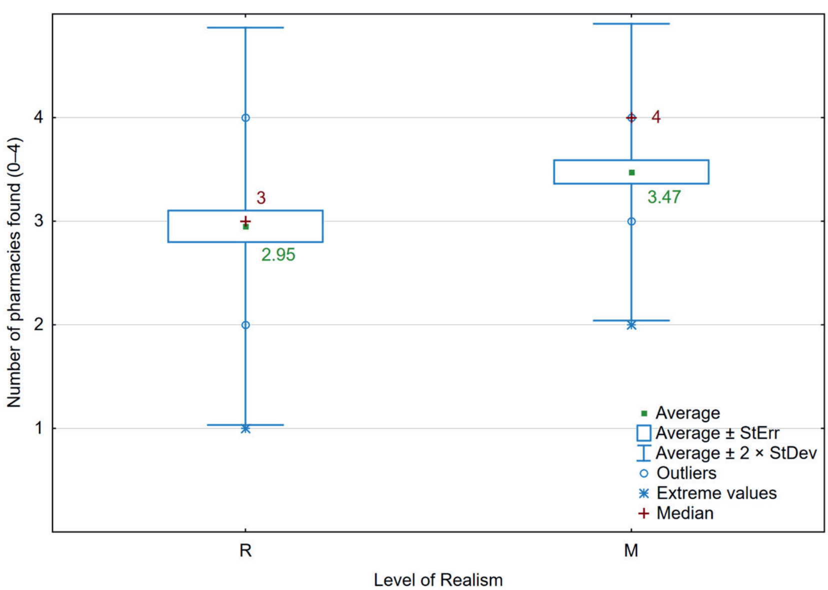


**Fig. 11** – Distances traveled and frequencies, averages (green numbers), and medians (red numbers) of the number of discovered pharmacies according to RealisticVE (R) and MixedVE (M). Source: authors.

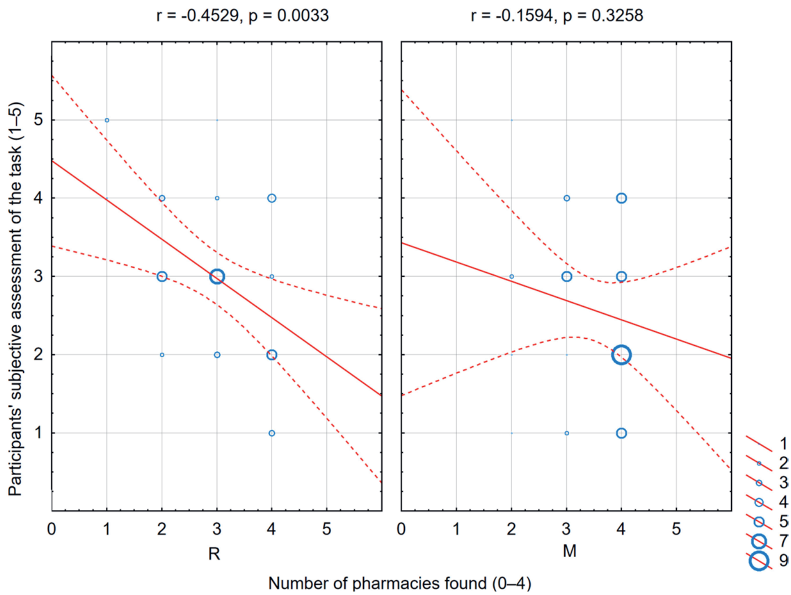


**Fig. 12** – Correlation diagrams of the number of discovered pharmacies (0–4) and the participants' subjective assessments (1 – easiest, 5 – most difficult) according to level of realism. Source: authors.

intense indirect correlation occurred with the RealisticVE, which has the largest negative correlation coefficient value ($r = -0.4529$). The statistical significance of the indirect correlation verifies the $p$-value ($p = 0.0033$). In the MixedVE, indirect correlation is also indicated ($r = -0.1594$) by a statistically insignificant $p$-value ($p = 0.3258$, Fig. 12).

Before the statistical analysis, the overdispersion of the data was verified as a variance-to-mean ratio. The result did not exceed the value of 1, therefore a Poisson GLM was applied. A comparison of the results for the MixedVE and RealisticVE using a Poisson GLM (Table 2) shows a statistically insignificant difference at the significance level $\alpha = 0.05$, where the $p$-value falls outside the limit for $\alpha$ in the critical range of values ($p = 0.191 < \alpha$).

**Table 2** – Statistical summary of the number of discovered pharmacies in the virtual environments

| Dependent variable:<br>The number of pharmacies: | Poisson Generalized Linear Model<br>Independent (grouping) variable: virtual environment (RealisticVE × MixedVE)<br>Coefficients: | | | |
|---|---|---|---|---|
| | Estimate Std. | Error | Z-value | Pr(>\|z\|) |
| MixedVE (Intercept) | 1.24559 | 0.08482 | 14.65 | <2e-16 |
| RealisticVE | −0.16379 | 0.12518 | −1.308 | 0.191 |

The results for the second task reveal that the participants discovered, on average, more pharmacies in the MixedVE than the RealisticVE, but the differences between the MixedVE and the RealisticVE are statistically insignificant. In the responses to the supplementary question concerning the strategy the participants applied to find the pharmacies, the most frequently mentioned keywords are *pharmacy*, *sign*, *cross*, *strategy*, *green*, *emblem*, *logo*, and *color*.

## 6. Discussion

3D visualizations offer many fields, including cartography, rich possibilities for use in scenarios such as user navigation, virtual city tours, etc. Cartographers, however, do not consistently agree on the effects of the level of realism and the level of detail on users' performance.

Many studies have examined differing levels of detail with applications in a range of fields, such as architecture (Chassin et al. 2022), emergency management (Sun, Zhou, Hou 2020) or spatial analyses (Biljecki et al. 2016). However, only a few studies address the level of detail from a user perspective. The results reported in the current study are, therefore, only applicable for comparison with the results of selected studies.

The current study investigated the effect of level of detail and level of realism on participants' perceptions of 3D visualizations and determined the most suitable level of detail for use with tasks in a given virtual environment. The study also examined the use of a geometric level of detail and a visual level of realism using textures in rendering the facades of buildings. The effects of level of detail and level of realism were tested on users in four virtual environments (1M, 1R, 2M, and 2R). The study followed a between-subject design and tested each virtual environment on a sample group of 80 participants with varied backgrounds, divided into four groups of 20. The participants performed two real-time tasks directly in the virtual environment using DesktopVR software.

The main results from our study can be summarized as follows:

a) First task: Participants identified more religious buildings on average in environments with higher levels of detail (LoD2), and there was a negative correlation between the number of identified religious buildings and the participants' subjective difficulty ratings. Despite statistical insignificance, this trend suggests perceptual ease in tasks as participants become more successful, which could have implications for virtual environment design and user experience.
b) Second task: The participants discovered more pharmacies in MixedVEs. It suggests that the blending of realistic and virtual elements may aid in task completion. There is an inverse relationship between the number of pharmacies

found and task difficulty ratings across virtual environments. The statistically significant correlation in RealisticVEs indicates a more pronounced perception of ease as success increases, contrasting with the MixedVE findings.

The results are in alignment with the study conducted by Shi et al. (2022); we concur that varying the level of detail has no impact on the participants' results. Conversely, our findings do not align with Lokka et al. (2018), who assert that different levels of realism affect results.

These differences between the studies could be due to:

- The variance in task types. Lokka et al. (2018) assessed the participants' recollection of routes, whereas the current study focused on searching for objects (while viewing from a predetermined location or by walking through the environment).
- The divergence in possibilities for interaction. Lokka et al. (2018) showed videos to participants, and therefore, they lacked control of movement. In the current study, participants were able to control their movements and directions of view.
- The differences in the participants' ages. Lokka et al. (2018) distinguished between age groups, and their results may have been affected by the participants' differences in age.

There are also limitations that could significantly affect the results of the task performed by the participant. In a possible follow-up study that would build on the results so far, it would be necessary to eliminate these limits as much as possible:

- Virtual environment processing quality – the virtual environments used in the current study rendered buildings with sharp edges and high visibility ambient light. Such details can affect user perception of objects, depending on the rendering quality in the virtual environment. We believe that this problem will be eliminated in the future by technological advances in hardware when high-performance devices will be more available.
- Type of task – the current study required the solution of two task types, but other types could deliver different results. A follow-up study could thus include a larger number of diverse tasks.
- Participants' abilities and expertise – the participants' task-solving strategies, decisions, and orientation in the virtual environment may have affected the results. Participants for the follow-up study should be selected in such a way that they already have experience with the virtual environment. We believe that it will not be difficult because the number of such people will increase.
- Time limit – the second task (finding pharmacies) applied a two-minute time limit, which some participants found stressful. In a follow-up study, the time limit should be set according to the difficulty of the task.

– Extent and complexity of the used virtual environment – the virtual environment mimics the layout of an actual town in Czechia (Bruntál), covering an area of 29 $km^2$. For other cities of different sizes and layouts, the results could vary. Other, larger, or more elaborated virtual environment can be used in a follow-up study.

## 7. Conclusion

The study explored the research question of whether the level of detail affects the user's perception of a 3D visualization. Analysis of the results for the first task indicates that the participants identified more religious buildings in LoD2 than in LoD1 by looking around from a single point in the virtual environment. However, the differences between LoD2 and LoD1 were statistically insignificant. Analysis of the results for individual tasks indicates that the level of detail had an insignificant effect on the user's perceptions of buildings in space. However, in addition to the level of detail, variables such as the level of realism in textures, colors, shadows, light, the extent of the virtual environment, and the complexity of tasks may also affect the user's ability to orient themselves within the environment.

While exploring a delineated area with a given time limit, the participants discovered more pharmacies in the MixedVE than in the RealisticVE. However, the differences between the MixedVE and the RealisticVE were statistically insignificant. Analysis of the results of the second task indicates that the MixedVE is not more suitable than the RealisticVE in finding a specific type of building.

Our study extends the examination of virtual environments to task-specific performance, providing insights into how environment detail and type influence the ability to identify objects within a virtual environment. This study adds to the body of knowledge on optimizing virtual environment design for navigational purposes, emphasizing the role of environment level of detail and level of realism.

Future work could involve verifying the results of the current study with a larger sample of participants. Other avenues of research in this area could include the use of immersive virtual reality devices (head-mounted displays with eye-tracking capability) and abstract virtual environments among the tested virtual environments to expand on findings, deliver new results, and probe other questions for study.

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