Towards evaluating the effects of visualization and task types on urban planning decisions

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Abstract

This study compares visualization types, i.e., 3D, 2D, Oblique 3D, and Combined 2D+3D, coupled in a pairwise fashion for different tasks and scenarios, and investigates their influence on decision-making across selected urban planning tasks. Specifically, we study *site selection*, *scenario selection*, and *distance estimation* as a baseline task which is relevant in both. In a controlled user study with 40 participants, we evaluate whether visualization type affects decision outcomes and distance estimation, complemented by participants’ visualization preferences *before* and *after* the experiment. The results confirm the previously well-documented evidence that participants are considerably more successful with distance estimation with 2D visualizations, and offers new evidence that decisions are affected by the examined visualization and task types. We observe that each visualization type exhibits distinct strengths depending on the task. These findings indicate that visualization choice in urban planning should be adapted to the task and context rather than treated as an interchangeable artifact.

1. Introduction

While 3D visualizations might offer higher intuitiveness due to their resemblance to everyday human experience (Ewald and Coors, 2005), two-dimensional (2D) representations offer a number of other advantages. This tension between abstraction and realism has been reflected in empirical experiments and people’s preferences, and is considered a persistent challenge (e.g., Çöltekin et al., 2015; Çöltekin et al., 2017) For example, 3D visualizations, due to their realism, enable ‘nameability’ of the represented objects, which could increase memorability, or increase spatial comprehensibility in certain cases where occlusion and perspective distortion supports depth perception (Herbert and Chen, 2015). There are also challenges related to the characteristics of 3D, e.g., occlusion can hinder visibility thus impair interpretation of the information, or the perspective distortion can lead to issues with distance estimation (Tory et al., 2004). On the other hand, 2D offers planar view, enabling easier (metric) distance estimations and an overview without occlusions or perspective distortions (e.g., Çöltekin et al., 2016; Jobst & Döllner, 2008). 2D however, arguably requires more cognitive processing due to abstraction and mental rotation. In summary, the way the information is visualized can drive the decision process (Dennis and Carte, 1998). In addition, Oblique 3D views (e.g., as captured by drones or cameras from a high vantage point) offer a “between” alternative to 2D and 3D, possibly suffering from disadvantages of both, and benefitting from advantages of both, depending on the context. In the context of urban planning, both 2D and 3D visualizations are commonly used for planning and collaborative decision making (e.g., Rautenbach et al., 2016). However, as outlined above, presenting spatial information in 2D or 3D can impact what information is perceived and processed, and in turn, affect decision outcomes (Schnürer et al., 2020; Biljecki et al., 2015; Çöltekin et al., 2016).

While it is understood that (spatial) dimensionality in visualizations matters in human performance with them, empirical evidence regarding how these visualization types affect decision outcomes in participatory urban planning is rare. Contributing to this gap, and given the strength of each visualization type, we examine the effects of 2D, 3D, a combination of the two (2D+3D) and an Oblique 3D (coupled in a pairwise fashion for different tasks and scenarios), on distance estimation (a fundamental task in spatial contexts including urban planning and architectural decision making) and decision making in selected urban planning scenarios in a controlled study with 40 non-expert participants simulating a participatory planning scenario. Specifically, we report the results for the following questions in this paper:

- **RQ1**: Which visualization type (*2D vs. Oblique 3D vs. 3D*) yields the most accurate distance estimations?
- **RQ2**: Is there a significant change in participants' decisions across two common urban decision-making tasks based on selected visualization and task types:
  a) *Combined 2D+3D* vs. *Oblique 3D* visualization types for a site selection task
  b) *2D vs. Oblique 3D* for a scenario selection task
- **RQ3**: Do participants' post-experiment preference ratings for the selected visualization types differ from their pre-experiment preference ratings?

Our **hypotheses** were as follows:

- **H1:** In connection to **RQ1**, based on prior work (e.g., Tory et al., 2004), we hypothesized that the 2D should facilitate the highest accuracy in distance estimation, possibly followed by the *Oblique 3D* (less occlusion, reduced perspective distortion in comparison to 3D), followed by first-person 3D.
- **H2:** In connection to **RQ2a**, for the *Site Selection* task, we compare *Combined 2D+3D* as information is needed from both 2D and 3D perspectives to solve the task. For this research question we hypothesized that the *Combined 2D+3D* view provides the highest amount of information, allowing for additional perspectives, thus might cause larger decision shifts than the *Oblique 3D* view.
- **H3:** For **RQ2b**, i.e., *Scenario Selection* task, we compare 2D vs. Oblique 3D because first-person 3D was simply not providing the necessary overview. In this case, Oblique 3D view contains elements from both 2D 3D views, and thus it should lead to more

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decision shifts than with 2D as it allows for a more realistic situational assessment.

- **H4:** For **RQ3**, we anticipate that people might prefer more *realistic* looking scenes (i.e., 3D or Oblique) given their relative proximity to the scenes of interest in the real world, as well prior work showing that people tend to prefer realistic displays (e.g., Smallman & Cook, 2011, Lokka et al., 2018).

2. Background

In recent years, the global push towards smart cities and the development of highly detailed digital twins made the need for accessible spatial data a priority for the citizens, especially to enable everyone to participate in decision making in architecture and urban planning (Lim, 2025; Peldon et al., 2024; Baumgartner et al., 2022). As municipalities increasingly rely on virtual replicas of physical objects for planning, ensuring that the public can interact with them meaningfully without specialized training has become essential (Luo et al., 2025). The participation of the local community in urban planning processes can provide valuable viewpoints that differ from the experts, especially because it captures people's lived experiences. In this context, the role of emerging technologies such as smart-phone or tablet based 3D visualizations and immersive technologies such as Extended (i.e., Virtual, Augmented and Mixed) Reality in participatory decision making for urban planning processes is interesting (Çöltekin et al., 2020; Brägger, et al., 2022; Proulx and Çöltekin, 2025), e.g., for enabling distributed participation (Baumgartner et al., 2022) or as novel paradigms for motivating the participation of younger citizens (Saßmannshausen et al., 2021).

However, for the above-outlined approaches to be useful, utilized technologies should facilitate spatial decision making well, and participants should *justifiably* feel confident in their ability to correctly understand and analyze the information that is presented to them. Frameworks such as Geodesign-integrated Geographic Information Systems (GIS), and other design tools proposed in the literature to translate complex environmental data into accessible formats highlight that the choice of visualization type is a critical factor in the participatory planning process (Snyman-van der Walt, 2023; Huskinson et al., 2025; Ernst, 2024). Using the right visualization type (or combinations of visualization types) with well-considered designs could allow both expert and non-expert participants to assess architectural and urban planning proposals while considering factors such as height, shadows, or the surrounding environment, and make more informed decisions. For example, Delaney (2000) shows that the communities who live in the affected neighborhoods prefer the proposed buildings to blend into the environment and not stand out.

Our initial review suggests that different visualization types support urban planning and architecture related decision making in complementary ways: 3D visualizations can be beneficial for operational tasks and for shape understanding (St. John et al., 2001), and 3D visualizations, especially stereo 3D supports the relative 3D position of objects where depth perception is relevant (McIntire et al., 2014) . Arguably, 3D representations can reduce the cognitive abstraction required by traditional maps, providing a more intuitive sense of scale and realism (Herman et al., 2025; Bittner et al., 2025).

Conversely, 3D visualizations introduce inherent geometric distortions and occlusion, and thus, can severely hamper the accurate estimation of angles and relative positions (Yan et al., 2025). Therefore, 2D visualizations seem to be more helpful for assessing relative planar positions and estimating distances (Jobst & Döllner, 2008), lengths, or in some cases, perhaps counterintuitively, evaluating steepness (Bleisch & Dykes, 2006). This dichotomy highlights a fundamental trade-off in spatial cognition: high realism (in this case, 3D visualizations) often comes at the expense of metric accuracy, forcing planners to choose between immersive public engagement and technical precision (Herman et al., 2025). To leverage the respective strengths of both dimensions, researchers have increasingly explored Combined 2D+3D and Oblique 3D views (Wei et al., 2024; Wang et al., 2025). Additionally, a small-sample study (n=8) suggested that by combining 2D and 3D approaches, it is possible to improve precise orientation and position tasks (Tory et al., 2004). Oblique views similarly offer a structural compromise, retaining a broad contextual overview while minimizing the severe occlusions and navigational complexities typical of immersive, first-person 3D perspectives (Zejdlik & Vozenilek, 2025). Not only oblique views are familiar from higher vantage points (buildings, bridges, hills) in everyday life, the recent proliferation of Unmanned Aerial Vehicles (UAVs) and advanced photogrammetry has made digital Oblique 3D models ubiquitous. As people are increasingly accustomed to seeing oblique views on commercial platforms such as Google Earth, it is possible that this perspective is among people's new digital habits, potentially reducing the learning curve during participatory workshops (Huang et al., 2025; Karahan et al., 2025). The ultimate measure of a visualization's utility in participatory urban planning is its impact on human cognition and behavior (Khogali et al., 2025).

According to the Cognitive Fit Theory (Vessey, 1991), when a spatial presentation format does not match the specific cognitive demands of the task, users are constrained by "bounded rationality", potentially leading to information overload and suboptimal planning decisions (Yang et al., 2025). When users are overwhelmed by navigating a complex 3D environment, their working memory is diverted away from the actual urban planning task, such as evaluating the functional impact of a new park, towards simply figuring out how to view the data (Sandor et al., 2025). Recent literature continues to explore subjective satisfaction and task performance in immersive environments; however, empirical evidence directly linking visualization formats to the final decision outcomes in participatory settings remains scarce (Bittner et al., 2025). In our work, we shift the focus from task performance to decision making, i.e., to whether 2D, 3D, Combined 2D+3D and Oblique 3D visualizations in varying pairwise comparisons, lead to different decisions, and the reasons behind these differences. By comparing these representations, we aim to provide actionable guidelines for minimizing cognitive overload and maximizing meaningful public participation.

3. Methods

Experiment design In a mixed factorial design experiment (all tasks within-, pairs of visualizations between-subjects), we compared the impact of selected visualizations on distance estimation, and two typical decision-making tasks involving a site selection and a scenario selection (further elaborated in the section *Procedure* below). We only coupled the visualization types when they were *informationally equivalent* (Larkin & Simon, 1987) for the task at hand, i.e., that the participants could find and see the necessary information as they worked with the visualization (Figure 1, Table 1).

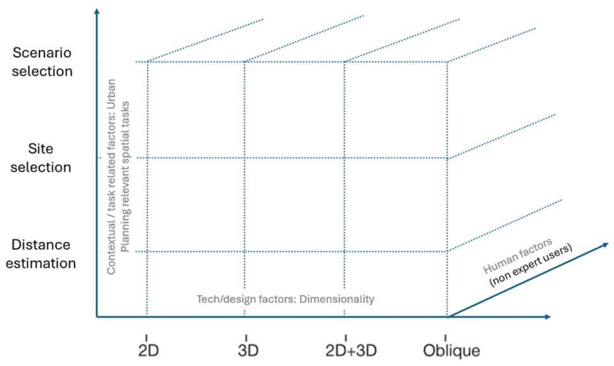

Figure 1. Experiment design (adapted to the framework by Cöltekin et al., 2019).

Task	Condition (visualization type)	Dependent Variables
Site Selection	Combined 2D+3D vs. Oblique 3D	Decision Shift, Preference
Scenario Selection	2D vs. Oblique 3D	Decision Shift, Preference
Distance Estimation	2D vs. Oblique 3D vs. 3D	Distance Estimation Accuracy, Preference

Table 1. The coupling of visualization types per task type and dependent variables measured in each condition reported in this paper.

Given our hypotheses (presented at the end of the *Introduction*), **independent variables** in the study were the *visualization* and *task types*, and in response, as dependent variables, we measured *distance estimation*, *decision shift*, and *preference*. We also recorded eye movement data to better analyze the attention patterns and cognitive process during decision making, though eye movement analysis is beyond the scope of this paper and will be presented in a follow-up publication.

Participants We conducted the experiment with 40 participants (age 18–45; 21 females, 19 males), recruited by word-of-mouth. The majority were undergraduate students at a university but had little to no experience in 3D graphics or urban planning.

Materials The stimuli for the experiment were 2D, 3D, Oblique 3D and Combined 2D+3D visualizations of city scenes. For the Site Selection task, a combination of 2D and first-person 3D visualizations (2D+3D) was used and compared against an Oblique 3D representation. This approach was adopted to ensure a comparable level of spatial information across conditions (i.e., *informationally equivalent*). In particular, the first-person 3D view limited the visibility of alternative locations due to occlusion, and the inclusion of the 2D representation helped compensate for this by providing an overview of all options. As a result, we considered the *Combined 2D+3D* condition comparable to the *Oblique 3D* visualization, where multiple locations could be perceived within a single view.

For the Scenario Selection task, a direct comparison between 2D and Oblique 3D visualizations was employed. In this case, both visualization types allowed participants to access the relevant design information for each proposal without substantial occlusion or loss of alternatives. Therefore, we considered a direct comparison appropriate, as both representations provided sufficient information to support decision-making. To conduct the study without bias from prior familiarity (e.g., if some of the participants are potentially more invested in the decisions than others), instead of using an existing city as the background, we created a fictional city in 3D, using Google SketchUp Make. The use of a purpose-built virtual environment offers several methodological advantages beyond eliminating recognition bias. First, it provides a fully controlled setting in which key environmental variables (e.g., solar angle and the resulting shadow patterns, the height and massing of architectural structures, and the degree of visual occlusion) can be systematically manipulated across conditions while all other factors remain constant. Second, using a fictional city removes the risk of political, cultural, or financial associations that participants might hold toward a real place, which could otherwise introduce confounding influences on their perceptual judgments. Third, the 3D model serves as a reusable and extensible research asset that can host interactive test environments, enabling future comparative studies within the same spatial framework, thereby ensuring consistency across experiments and reducing the overhead of developing new stimuli. For the 2D visualization, we used the top views of the same surface area using parallel projection of the 3D visualizations with the shadows disabled. Combined 2D+3D vive, as the name implies, combines 2D and 3D side by side, and lastly, we created Oblique 3D views that provided an in-between of the content and realism.

Procedure After filling in a demographic questionnaire and signing the consent form, before the experiment, participants were asked to indicate their preferred visualization type amongst 2D, 3D, Combined 2D+3D and Oblique 3D for different urban planning scenarios. Subsequently, users completed three different urban planning tasks in a randomized sequence where order in which the visualizations were shown was also systematically rotated:

1) Site Selection Task: For this task, we asked the participants “*Imagine that this is your neighborhood. A new residential, high-rise building (skyscraper) will be built. Four alternative locations are proposed. Please choose the location that you think is best suited for the building. Possible locations are indicated with a red square and the letters A–D.*” Participants were presented with four Combined 2D+3D views, each displaying the same 2D section alongside a first-person 3D view corresponding to one of four sites (A, B, C, and D), as illustrated in Figure 2 (top) for location A. Upon completing their evaluations across all four locations, participants were then shown the Oblique 3D view of the neighborhood (Figure 2, bottom) and asked to reconsider their decisions.

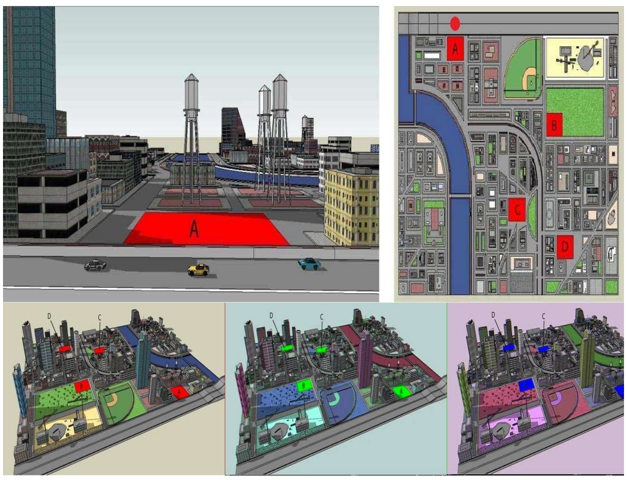

Figure 2. Site selection task, **Scene 1**, with Combined 2D+3D for location A (top), and Oblique 3D (bottom) views.

Once they completed this first scene, to obtain 'repeated measures' we gave them a second scene, a different neighborhood, asking the same question containing possible locations labelled from E to H (Figure 3).

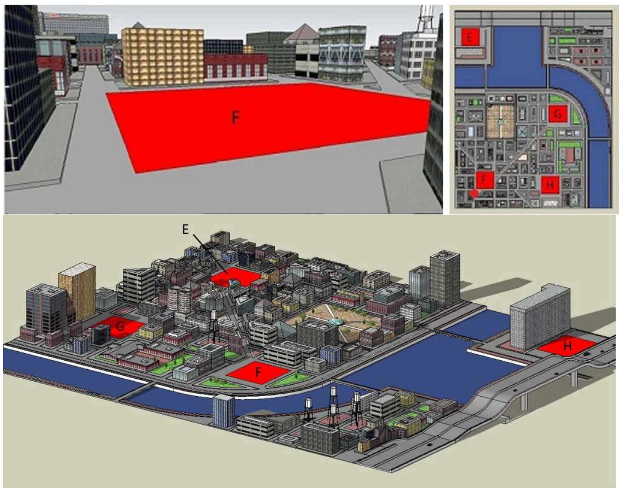

Figure 3. Site selection task, **Scene 2**, with Combined 2D+3D for location F (top), and Oblique 3D (bottom) views.

2) Scenario Selection Task: In this task, we presented participants two alternative design proposals for a park using 2D and the Oblique 3D views (Figure 4) and asked "*Your neighborhood park is being redesigned. You will now see two alternative proposals for your new park design. You, as a citizen, can decide which of the two alternatives should be realized through a vote.*" For each proposal, both design options were presented using a single visualization type at a time. We performed the same approach for another design project where users selected between design alternatives of a playground (Figure 5).

3) Distance Estimation Task: As an implicit task that humans execute through all spatial tasks, distance estimation is also necessary to plan and evaluate urban plans correctly. For this task, we marked two points (A, B) on 2D, 3D, and Oblique 3D visualizations and asked the participants to estimate the walking distance in meters between these points for each visualization type (Figure 6).

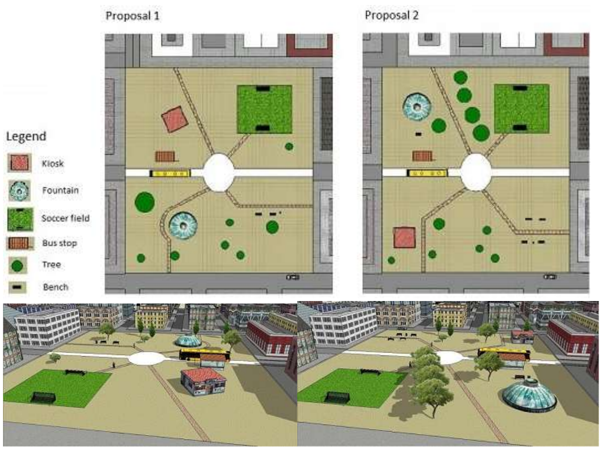

Figure 4. Scenario selection task **Scene 1** (park design) with 2D (top) and Oblique 3D (bottom) views.

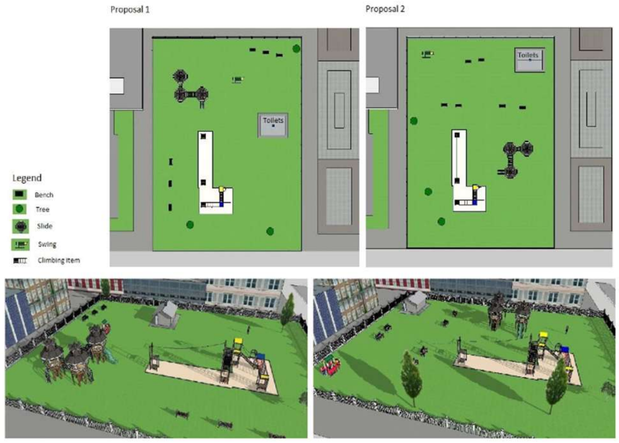

Figure 5. Scenario selection task **Scene 2** (playground) with 2D (top) and Oblique 3D (bottom) views.

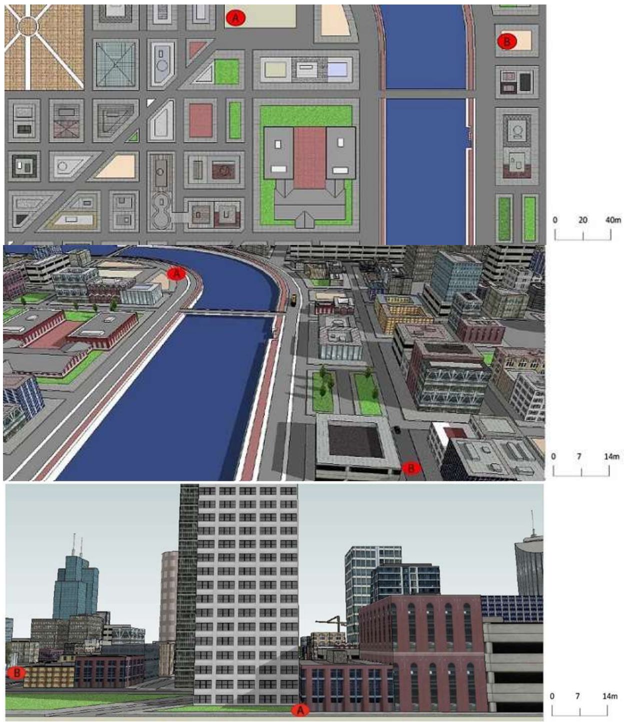

Figure 6. Distance estimation examples for 2D (top), Oblique 3D (middle) and 3D views (bottom). A graphical scale has been shown in all conditions, and locations were kept constant.

In the last part of the experiment, we once again asked participants' preference of visualization types in connection to the tasks, as we assumed there may be changes after they worked with actual tasks. Additionally, we recorded participants' eye movements, and after each task, we asked the users to rate the difficulty of each visualization type, and surveyed their satisfaction using a five-point Likert scale where they rated the usefulness and attractiveness of each visualization type (these additional measures are not reported in this paper due to page limits).

4. Results

Decision shifts and visualization type

For the *Site Selection Task*, we compared *Combined 2D+3D* and *Oblique 3D* over two scenes (different neighborhoods). Participants selected the best of four sites (Scene 1: A-D) and

(Scene 2: E-H) for a proposed high-rise building. Scene 1 (Figure 2) (t = 0.99, **p = 0.32**) showed no significant difference between visualization types (10% decision shift, 95% CI [0.7%, 19.3% upper and lower bound SEM], Cohen's g=0.5), while Scene 2 (Figure 3) (t = -2.17, **p = 0.03***) produced a significant effect (42.5% decision shift, 95% CI [27.2%, 57.8% upper and lower bound SEM], Cohen's g=0.5). A comparison across scenes further indicated that decision-change behavior differed significantly between Scene 1 and Scene 2 (***p* = .0002*****, Cohen's d=0.65), suggesting that the effect of visualization depends on the scene (Figure 7, left).

For the *Scenario Selection Task,* we compared 2D vs. Oblique 3D, again over two different scenes for repeated measures. Here we observe a similar pattern: participants' decisions shifted depending on the visualization type. In the first scene, 27.5% of participants showed divergent preferences across conditions (95% CI [13.7%, 41.3% upper and lower bound SEM], Cohen's g=0.5). A chi-square test of independence indicated a statistically significant association between the visualization type and participants' scenario choices in scene 1 ($\chi^2(12, N = 40) = 26.305$, **p = 0.010**,** Cohen's d = 0.11). Similarly, in the second scene, the decision shift was 22.5% (95% CI [9.6%, 35.4% upper and lower bound SEM], Cohen's g=0.5). A chi-square test was again performed to examine the relationship between proposals in 2D and 3D visualizations for the playgrounds. The results indicated a statistically significant association between the type of visualization and participants' scenario choices, $\chi^2(12, N = 40) = 38.540$, **p < .001*****. However, when comparing across scenes, no statistically significant difference in decision-change behavior was observed (p = .50), indicating that the influence of visualization type was consistent across scenes in this task (Figure 7, right).

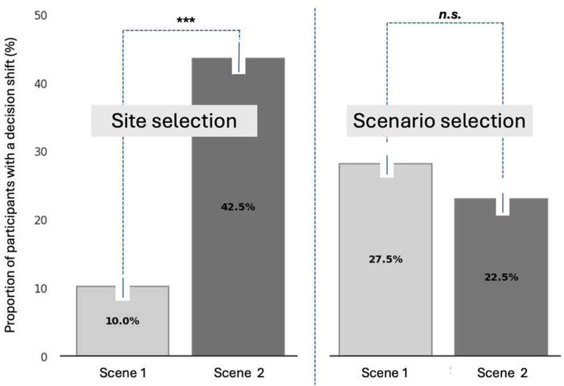

Figure 7. Effects of the *task type* based on different scenes on decision making. Error bars ∓SEM, ***p<.01, *n.s.* = not significant. Please note that the vertical axis is cut off at 50% for better readability.

When we examine the data with more specific detail for the compared visualizations in connection to specific locations, we see that the observed effects are mostly attributable to specific locations in the Site Selection task (Figures 8). In the Scenario Selection task (Figure 9), the specific scenario (selecting a park vs a playground) makes a major difference. Figure 8 shows that in Scene 1, for the Site Selection task ("*where should the high-rise buildings go?*"), majority of participants selected Location D with both visualization types, and only 5% shifted their decision to Location A when shown the Oblique 3D. In Scene 2, we see much higher variation in the decisions between the two visualization conditions. Most prominently, with Oblique 3D, half of the participants agree on Location H, while with 2D+3D, Location H was preferred only by 22.5% of the participants. These statistics are reported only descriptively (no inferential statistics) as once split into smaller bins, the power is not sufficient, especially with unbalanced classes.

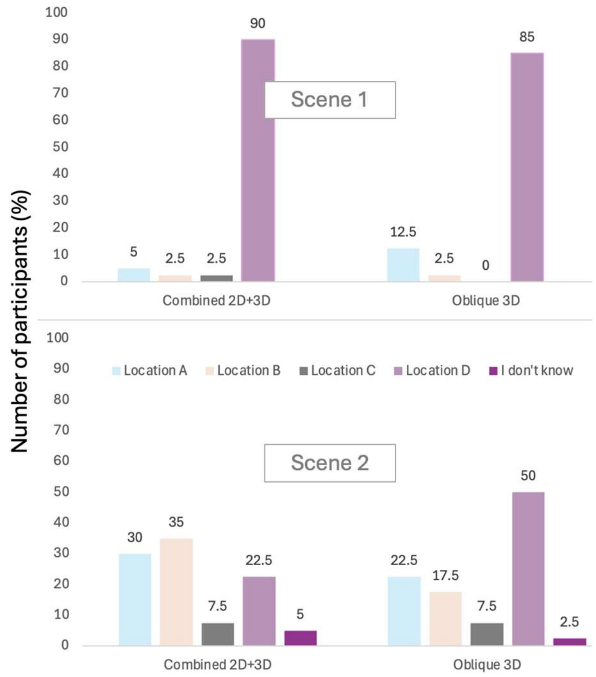

Figure 8. Decision shifts per visualization type, split by scene and specific locations.

Figure 9 shows that for the Scenario selection task, when examined by the specific scenarios, i.e., *"which proposal would you choose for the new park*" (top), we see that 2D led to no changes, while Oblique 3D led to a 50% of the participants shift their decisions. For playground (bottom) the effect is more subtle with 12.5% for 2D and 5% for Oblique 3D.

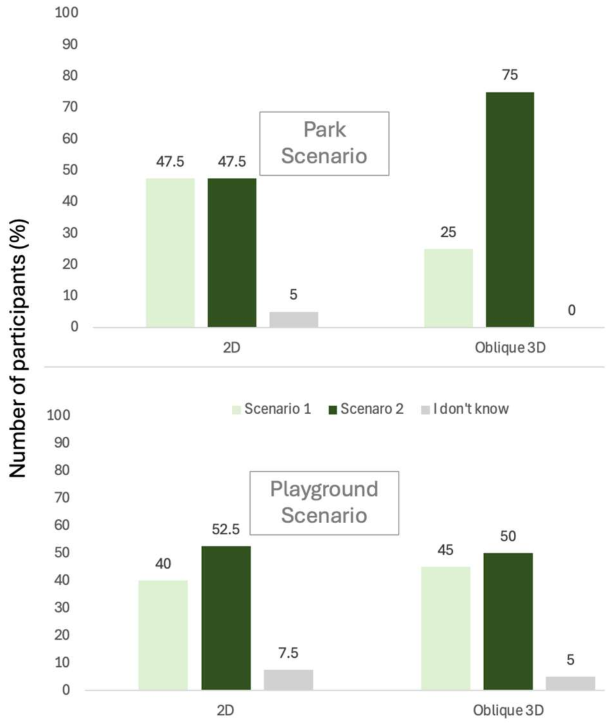

Figure 9. Decision shifts per visualization type, split by scenario.

Distance Estimation Task

For the *Distance Estimation Task*, we classified accuracy relative to the actual distance as *good* (<11 m), *moderate* (11–50 m), or *poor* (>50 m), as we deem this level of precision sufficient for the context at hand. Based on this classification, participant performance varied substantially across visualization types. The 2D map yielded the highest accuracy, with 80% of estimates falling in the *good* range, 15% *moderate*, and only 5% *poor*. The Oblique 3D view showed a more distributed pattern, with 30% *good*, 45% *moderate*, and 25% *poor* estimates. Accuracy was lowest in the 3D First-Person condition, where half of all estimates were classified as *poor*, and only 20% reached the *good* threshold. Participants achieved higher accuracy with the 2D visualization compared to the 3D types ($F(2, 158) = 88.307$, **p < .01****). Pairwise comparisons revealed statistical differences in two out of three comparisons: 2D vs Oblique 3D (**p = 0.04***, Cohen's d = 0.882), and also to 3D (**p = 0.002**, Cohen’s d = 1.3), whereas Oblique 3D vs. 3D did not reveal significant effects (p = 0.242, Cohen’s d = 0.456). The

Preference

We asked the participants which type of visualization they would *prefer* at the start and end of the experiment. Figure 10 shows an aggregate view of their before/after preferences for the two visualization types that are direct alternatives to each other, *Oblique 3D* and *Combined 2D+3D*. As seen in Figure 10, results demonstrate a major shift, 87.5% of the participants indicated that they would use Oblique 3D for urban-planning-related decisions (**p < 0.001*****, Cohen's g = 0.50) after the experiment, which is more than twice as much as *before* the experiment. We also see that preference for the Combined 2D+3D view dropped from 40% to 12.5%, also a significant finding with a high effects size (**p = 0.001*****, Cohen's g = 0.50).

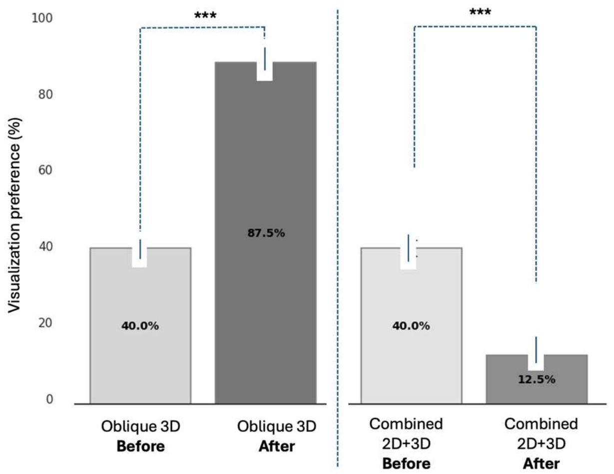

Figure 10. Shift in *preference* for visualization types at an aggregate level before and after the experiment. Error bars ∓SEM, ***p<.001

At the task level, we see that participants’ visualization preferences were also affected by task type, both before and after the experiment (Figure 11). We present these results only as descriptive statistics, as splitting them weakens the statistical power. What is evident in Figure 11 is that the variation is relatively mild with the Distance Estimation task, with a 10% shift towards 2D after the experiment (5% from each of the other alternatives inquired). For the two selection tasks, we see a considerable shift to Oblique 3D after the experiment, as it also was evident in the main effects reported in Figure 10.

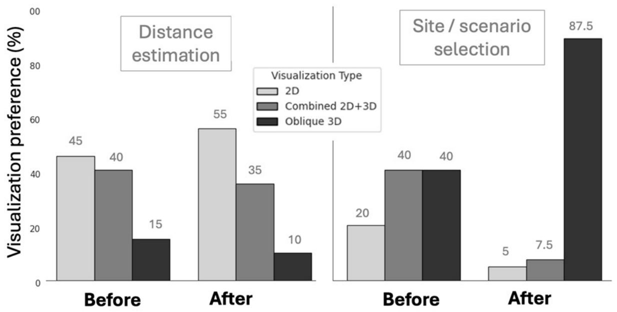

Figure 11. Participant preferences of visualization type before and after the experiment, split by task type.

5. Discussion

We set out to explore if changing visualization types would change people’s decisions in the context of urban planning, with a set of selected tasks and visualization types. In addition, we compared the participants’ performance in a distance estimation task – a fundamental task in spatial contexts, and a baseline task for this experiment, as we assumed people are very likely trying to (implicitly or explicitly) estimate how far the planned interventions are from certain points of interest. Based on empirical evidence in previous work, we also formulated four hypotheses, which are revisited below.

Distance estimation results (RQ1) provide new evidence further affirming the prior work (e.g., Jobst & Döllner, 2008; Bleisch & Dykes, 2006): As it was anticipated, the 2D views facilitated a distinctively more accurate distance estimation for the participants compared to the two other visualization types which both contain the weaknesses of 3D (occlusion, perspective distortion) in different degrees. Oblique 3D views facilitated slightly higher distance estimation accuracy (not statistically significant) than the 3D condition, which may be attributed to the greater levels of distortion and occlusion present in first-person 3D perspectives, as also noted by Yan et al. (2025). Thus, we retain our H1 “*2D* should facilitate the highest accuracy in distance estimation, possibly followed by *Oblique 3D* (less occlusion, reduced perspective distortion in comparison to 3D), followed by first-person *3D*”.

Regarding **decision shifts** (RQ2), our first observation was that they were highly task dependent. Given also that we coupled different visualization types that made sense (i.e., were informationally equivalent) for different tasks, in essence the study was designed rather as a series of mini experiments. Taking this specific experiment design, below we provide the interpretations at the task level.

For the **Site Selection task** (RQ2a), in Scene 1, only 10% of participants changed their decisions, and across both visualization types, Location D was the preferred site for the high-rise. Participant comments such as “*At location D, the building will already be around other skyscrapers (no obstruction of the landscape)*” and “*The visual impact as well as the affected surrounding space would be minimized at location D since it is already surrounded by high-rises*” indicate that participants favored this option due to its similarity to the existing urban context. This aligns with findings by Delaney (2000), which suggest that the public prefers architectural developments that integrate with their surroundings. According to Dennis &

Carte (1998), the type of visual will have an impact on the decision makers. While the results from Scene 1 do not support this claim, Scene 2 shows a significant shift in participant choices (42.5%). The reason for this could be that for Scene 1, both the first-person *Combined 3D+2D* and the *Oblique 3D* views were able to show a distinguishable high-rise zone for Location D. In contrast, for Scene 2, participants selecting from the *Oblique 3D* visualization predominantly chose Location H, whereas selections based on the *Combined 3D+2D* visualizations were more distributed, with locations E and F more frequently preferred. One possible explanation is that the first-person 3D views (which are included in the *Combined 3D+2D*) convey a different impression of surrounding high-rise density and the height of the buildings compared to the Oblique 3D, which may have influenced participants' perception of suitability. Compared to Scene 1, these spatial relationships appear to be less clearly distinguishable, suggesting that the effect of the first-person perspective may be more ambiguous in more complex or less legible environments. Site selection tasks reveal that visualization types do not have a universal effect but interacts with the properties of the content being evaluated. Given these observations, our data does not sufficiently support our H2: **"***Combined 2D+3D* view provides the highest amount of information, allowing for additional perspectives, thus might cause the larger decision shifts than the Oblique *3D* view"

For the **Scenario Selection task** (RQ2b), *2D* maps were compared with *Oblique 3D* visualizations of two design proposals across two scenarios, where Scene 1 showed significant decision shifts. As noted by Herman et al. (2025) and Brittner et al. (2025), 3D visualizations provide a more intuitive sense of realism. The results support this claim: although both the *2D* and *Oblique 3D* representations included the same number of trees, participant comments indicate that dimensionality had a stronger visual impact in the 3D condition ("*the trees provide shadow*"). For Scene 1, a clearer level of decisiveness is observed when participants are presented with *Oblique 3D* visualizations. selections based on the 2D representation were evenly distributed between the two proposals, with a small proportion of participants (5%) indicating uncertainty ("I don't know"), suggesting that the 2D visualization may not have conveyed the design differences consistently across participants. In contrast, when viewing the *Oblique 3D* representation, a substantial majority of participants (75%) selected the second proposal, and no participants expressed uncertainty. Also in support of this, we observe that fewer participants reported uncertainty for the *Oblique 3D* than for *2D*. An important difference emerges when considering both scenes of the Scenario Selection task together. While Scene 1 showed a clear shift toward more decisive and convergent choices under the Oblique 3D visualization, this pattern was less pronounced in Scene 2. However, when comparing across scenes, no significant difference in decision change was found. Unlike the Site Selection tasks, the effect of visualization type is stable across different contexts in this task. As an additional consideration, given that the target group consisted of non-experts, it is likely that the Oblique 3D visualizations (due to their realism) made it easier to interpret the ambiance and aesthetic qualities of the scene compared to the 2D plans (*"More trees. Kiosk should not be in the middle of the park.. waste of space*"). In contrast to the participant comments for the Oblique 3D view, responses to the 2D view indicate that participants primarily based their interpretations on distance relationships ("*because the Kiosk is closer to the soccer field*") supporting e.g., Jobst & Döllner (2008) that hat 2D visualizations are more effective for assessing relative (planar) positions and estimating distances. These results indicate that the Oblique 3D view can give more context and space in public participation scenarios to interpret and discuss the given proposals more realistically. In the light of these findings, overall we can retain our H3: "Oblique 3D view contains elements from both 2D 3D views, and thus it should lead to more decision shifts than with 2D as it allows for a more realistic situational assessment."

Overall, for these two decision tasks (Site Selection & Scenario Selection), the main findings suggest that visualization type matter when the relevant spatial information is perceptually salient or not. Conversely, visualization type might not matter when one option is overwhelmingly dominant due to contextual considerations, or when both visualization types convey decision-relevant information in an equally salient fashion. A follow-up analysis of eye movement data (which was collected in this experiment but not reported in this paper due to the scope limitations) might allow for deeper insights on the interpretation of the decision shifts.

In terms of **preference** (RQ3), we see that for the Distance Estimation task, participants indicated that they preferred 2D most both before and after the experiment. Markedly, we see a 10% shift in preference favoring 2D visualizations after the experiment. It is noteworthy that the second-most preferred option (Combined 2D+3D) for Distance Estimation also includes a 2D planar view. As participants did not receive explicit performance feedback (i.e., they were not told how well they were doing during the experiment), this shift likely reflects an implicit self-assessment reflecting the task experience (i.e., participants did a lot better with 2D for Distance Estimation tasks), suggesting higher metacognitive abilities for those who have shifted their preference to 2D after the experiment. In connection to this speculation, one possible explanation is that participants relied on internal cues such as ease of processing when forming preferences (Reber et al., 2004). While metacognitive processes cannot be directly measured, the observed shift is consistent with preference updating based on internal task experience. Nonetheless, as participants stated for previous tasks (i.e. "*not a good view for such decisions, [playground scenario] difficult to imagine*"), 2D views lack dimensionality for further urban planning activities as a single visual source. For the Site and Scenario Selection tasks, we see a major shift in participant preferences between before-and-after experiments in favor of Oblique 3D. Taken together, based on these outcomes, we can only partially retain our H4 "people might prefer more *realistic* looking scenes (i.e., 3D or Oblique) given their relative proximity to the scenes of interest in the real world, as well prior work showing that people tend to prefer realistic displays (e.g., Smallman & Cook, 2011, Lokka et al., 2018)." – i.e., our H4 holds for the Site and Scenario Selection tasks overall, but not for the Distance Estimation task. Given that 3D views hold relevant information for the selection tasks, and 2D is better for the Distance estimation task, the observations in this experiment do not suggest a case of *näive realism*.

6. Conclusion and Outlook

We examined the effectiveness of 2D, 3D, Oblique 3D and Combined 2D+3D visualizations in selected urban planning related decision-making tasks as well as in a fundamental spatial task (distance estimation). Our controlled user experiment with 40 participants was designed to investigate how selected visualization types commonly used in urban planning influenced distance estimation accuracy and decision processes across two tasks (site selection, scenario selection). In the Distance Estimation tasks, as expected, 2D offers clear advantages, and participants broadly also favor the 2D. For the Site and Scenario

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selection tasks, participants overall favored the Oblique 3D visualization *after* they went through the experiment. Taken together, outcomes show dependencies not only on visualization types, but also on task types and specific scenes. These initial observations underline the importance of nuanced considerations and analyses rather than 'blanket statements' regarding visualization types and their effect on decision making in general, and in urban planning related decision making in particular.

Future research could explore more complex, scenario-based urban planning questions that invite participants to critically engage with real design challenges and policy trade-offs. Identifying which combinations of visual formats best support deeper deliberation across different planning scenarios remains a promising avenue. While offering a broad range of visualizations may seem advantageous, the inclusion of redundant or mismatched formats should be avoided, as representations that do not align with the cognitive demands of a given task risk inducing information overload and shifting users' attention away from the substantive planning task toward the navigational demands of the visualization itself.

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References

Baumgartner, L., Brägger, L., Koebel, K., Scheidegger, J., and Çöltekin, A.: Visually Annotated Responsive Digital Twins For Remote Collaboration In Mixed Reality Environments, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-4-2022, 329–336, doi: 10.5194/isprs-annals-V-4-2022-329-2022, 2022.

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. doi: 10.3390/ijgi4042842

Bittner, O., Zejdlik, J., Burian, J., & Vozenilek, V. (2025). Exploring unconventional 3D geovisualization methods for land suitability assessment: A case study of Jihlava City. ISPRS International Journal of Geo-Information, 14(7), 269.

Bleisch, S., & Dykes, J. (2006, April 5). Planning Hikes Virtually: How Useful are Webbased 3D Visualizations? GIS Research UK 14th Annual Conference (GISRUK 2006), University of Nottingham, Nottingham, UK. https://openaccess.city.ac.uk/id/eprint/401

Brägger, L., Baumgartner, L., Koebel, K., Scheidegger, J., and Çöltekin, A.: Interaction And Visualization Design Considerations For Gaze-Guided Communication In Collaborative Extended Reality, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-4-2022, 205–212, doi: 10.5194/isprs-annals-V-4-2022-205-2022, 2022.

Çöltekin, A. (2019). What contributes to the complexity of visuospatial displays? Abstraction, Scale and Perception. International Cartographic Association Joint Commission Workshop.

Çöltekin, A., Bleisch, S., Andrienko, G., & Dykes, J. (2017). Persistent challenges in geovisualization–a community perspective. International Journal of Cartography, 3(sup1), 115-139. doi: 10.1080/23729333.2017.1302910

Çöltekin, A., Lochhead, I., Madden, M., Christophe, S., Devaux, A., Pettit, C., ... & Hedley, N. (2020). Extended reality in spatial sciences: A review of research challenges and future directions. ISPRS International Journal of Geo-Information, 9(7), 439. doi: 10.3390/ijgi9070439

Çöltekin, A., Lokka, I. E., & Boér, A. (2015, August). The utilization of publicly available map types by non-experts—A choice experiment. In Proceedings of the 27th International Cartographic Conference (ICC2015), Rio de Janeiro, Brazil (pp. 23-28). doi: 10.5167/UZH-117966

Çöltekin, A., Lokka, I.-E., & Zahner, M. (2016). On the usability and usefulness of 3D (geo)visualizations -- A focus on virtual reality environments. *International Archives of the ISPRS*. doi: 10.5194/isprs-archives-XLI-B2-387-2016

Delaney, B. (2000). Visualization in Urban Planning: They Didn't Build LA in a Day. IEEE Comput. Graph. Appl., 20(3), 10–16. doi: 10.1109/38.844365

Dennis, A. R., & Carte, T. (1998). Using Geographical Information Systems for Decision Making: Extending Cognitive Fit Theory to Map-Based Presentations. Inf. Syst. Res., 9, 194–203.

Ernst, F. (2024). Geodesign for Designing the Future of Our Cities. GSI Journals Serie C: Advancements in Information Sciences and Technologies, 6(2), 1-19.

Ewald, K., & Coors, V. (2005). Appraisal of Standards for 3D City Models. Proceedings of the Ninth International Conference on Information Visualisation, 157–162. doi: 10.1109/IV.2005.21

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. doi: 10.1080/15230406.2014.987694

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

Huang, Y., Lieberherr, E., Nandee, K., Bounithiphonh, C., Krähenbühl, J., Sichanthongthip, P., & Kleinschroth, F. (2025). Aerial imagery to support participatory landscape decision-making. Earth System Governance, 26, 100287.

Huskinson, M., Bernabeu-Bautista, Á., Campagna, M., & Serrano-Estrada, L. (2025). Co-Designing Accessible Urban Public Spaces Through Geodesign: A Case Study of Alicante, Spain. Land, 14(10), 2072.

Larkin, J.H., Simon, H.A., Why a Diagram is (Sometimes) Worth Ten Thousand Words, Cognitive Science, Volume 11, Issue 1, 1987, Pages 65-100, ISSN 0364-0213, doi: 10.1016/S0364-0213(87)80026-5.

Jobst, M., & Döllner, J. (2008). 3D City Model Visualization with Cartography-Oriented Design (M. Schrenk & Verein CORP - Competence Center of Urban and Regional Planning, Eds.). REAL CORP, Schwechat-Rannersdorf. CORP, Competence Center of Urban and Regional Planning.

Karahan, A., Gökçe, O., Demircan, N., Özgeriş, M., & Karahan, F. (2025). Integrating UAV photogrammetry and GIS to assess terrace landscapes in mountainous northeastern Türkiye for sustainable land management. Sustainability, 17(13), 5855.

Khogali, M. M., Mohamed Ali, E. A., & Ramdani, A. (2025). Integrating behavioral science into urban planning: a framework for human-centered spatial design. Frontiers in Psychology, 16, 1632523.

Lim, F. P. C. (2025). Smart City Planning through Digital Twins: Enhancing Urban Resilience and Sustainability. International Journal of Science, Architecture, Technology, and Environment.

Lokka, I. E., Çöltekin, A., Wiener, J., Fabrikant, S. I., & Röcke, C. (2018). Virtual environments as memory training devices in navigational tasks for older adults. Scientific Reports, 8(1), 10809. doi: 10.1038/s41598-018-29029-x

Luo, J., Liu, P., Kong, X., Shen, J., Wu, Q., & Xu, D. (2025). Urban digital twins for citizen-centric planning: A systematic review of built environment perception and public participation. International Journal of Applied Earth Observation and Geoinformation, 143, 104746.

McIntire, J. P., Havig, P. R., & Geiselman, E. E. (2014). Stereoscopic 3D displays and human performance: A comprehensive review. Displays, 35(1), 18-26. doi: 10.1016/j.displa.2013.10.004

Peldon, D., Banihashemi, S., LeNguyen, K., & Derrible, S. (2024). Navigating urban complexity: The transformative role of digital twins in smart city development. Sustainable Cities and Society.

Proulx MJ and Çöltekin A (2025) Editorial: Use of immersive technologies in design. Front. Comput. Sci. 7:1620569. doi: 10.3389/fcomp.2025.1620569

Rautenbach, V., Coetzee, S., & Çöltekin, A. (2016). Investigating the use of 3D geovisualizations for urban design in informal settlement upgrading in South Africa. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 41, 425-431.

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience? Personality and Social Psychology Review. doi: 10.1207/s15327957pspr0804_3

Sandor, V., Kostourou, F., Fink, T., & Düring, S. (2025). Phygital Co-Creation: A Hybrid Approach for Enhancing Participatory Urban Planning in Early Design Stages. Journal of Digital Landscape Architecture, 10, 35-44.

Saßmannshausen, S. M., Radtke, J., Bohn, N., Hussein, H., Randall, D., & Pipek, V. (2021). Citizen-Centered Design in Urban Planning: How Augmented Reality can be used in Citizen Participation Processes. Designing Interactive Systems Conference 2021, 250–265. doi: 10.1145/3461778.3462130

Schnürer, R., Ritzi, M., Çöltekin, A., & Sieber, R. (2020). An empirical evaluation of three-dimensional pie charts with individually extruded sectors in a geovisualization context. Information Visualization, 19(3), 183-206. doi: 10.1177/1473871619896

Smallman, H. S., & Cook, M. B. (2011). Naïve realism: Folk fallacies in the design and use of visual displays. Topics in cognitive science, 3(3), 579-608. doi: 10.1111/j.1756-8765.2010.01114.x

Snyman-van der Walt, L. (2023, September). Geodesign as a Supplementary Tool to Strategic Environmental Assessment. In International Conference on Innovation in Urban and Regional Planning (pp. 59-67). Cham: Springer Nature Switzerland.

St. John, M., Cowen, M. B., Smallman, H. S., & Oonk, H. M. (2001). The Use of 2D and 3D Displays for Shape-Understanding versus Relative-Position Tasks. Human Factors: The Journal of the Human Factors and Ergonomics Society, 43(1), 79–98. doi: 10.1518/001872001775992534

Tory, M., Moller, T., Atkins, M. S., & Kirkpatrick, A. E. (2004). Combining 2D and 3D views for orientation and relative position tasks. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 73–80. doi: 10.1145/985692.985702

Vessey, I. (1991). Cognitive fit: A theory-based analysis of the graphs versus tables literature. Decision sciences, 22(2), 219-240. doi: 10.1111/j.1540-5915.1991.tb00344.x

Wang, X., Zhou, L., Song, Y., López-Carr, D., Wang, S., Chen, H., ... & Wei, W. (2025). Beyond flat cities: dramatic 2D/3D differences in urban gray–green space configurations and the nonlinear thermal regulation mechanisms. GIScience & Remote Sensing, 62(1), 2572174.

Wei, X., Sun, Y., Li, H., Lin, H., & Tang, C. (2024). Research and Application of 3D Real Modelling from Oblique Images for City Planning. Advances in Computer and Materials Science Research, 1(1), 301-310.

Yan, Y., Huang, B., Wang, W., Jiang, X., Xie, L., Pun, M. O., ... & Zhao, Y. (2025). Towards vertical urban geometry extraction: occlusion-reduced estimation from street view images using diffusion models. International Journal of Digital Earth, 18(1), 2520475.

Yang, F., Shen, J., Zhu, F., & Zhang, J. (2025). A cartographic generalization method for 3D visualization of trajectories in space–time cubes: case study of epidemic spread. International Journal of Digital Earth, 18(1), 2474190.

Zejdlik, J., & Vozenilek, V. (2025). Methods of 3D geovisualization of thematic data in the context of graphic variables. International Journal of Cartography, 1-16.