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Published in:
Landscape and Urban Planning

DOI:
10.1016/j.landurbplan.2023.104716

Published: 01/06/2023

Document Version
Publisher's PDF, also known as Version of record

Landscape and Urban Planning 234 (2023) 104716

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Review Article

3D visualisations for communicative urban and landscape planning: What systematic mapping of academic literature can tell us of their potential?

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H I G H L I G H T S

- Only a few cases exist where 3D use was studied in real-life planning processes.
- Robust usability evaluations with end users are rare.
- Due to heterogeneity in the field a framework for case study reporting is suggested.
- Research should critically evaluate usability for communicative planning purposes.

A R T I C L E I N F O

Keywords:
3D model
Collaborative planning
Digital twin
Land use planning
Participation
Spatial planning

A B S T R A C T

Public participation and collaboration supported by the opportunities that digital technologies offer are prolific themes in urban and landscape planning. In the past two decades, there has been a growing interest in the capacity of 3D visualisations to support citizen and stakeholder engagement in communicative planning processes. However, the technical advances of 3D visualisations still outstrip the current understanding of their benefits, appropriate uses and usability in practical planning contexts. There are no reviews or systematic mapping of literature, to our knowledge, that investigate the available evidence on the usability of particular 3D visualisations or that document the scope and gaps in current research on 3D applications in communicative planning. To answer this need we conducted a systematic mapping of academic literature reporting recent case studies of 3D visualisations that have been utilised or developed for communicative urban and landscape planning contexts. We follow established guidelines for systematic reviews and used Scopus and Web of Science as primary electronic databases. Altogether, we reviewed 46 case studies globally. Our findings highlight the heterogeneity of planning contexts and purposes, terminology and technological 3D solutions. Moreover, the scarcity of real-life planning cases and robust and well-documented usability evaluations are evident in the literature. We discuss limitations of the existing academic literature for evidence-based understanding and suggest a common framework for reporting in the field of participatory and collaborative 3D visualisations to enable more rigorous and systematic evaluation of the usability and benefits of these technologies in urban and landscape planning.

1. Introduction

Public participation and collaboration have become mainstream discussion points in urban and landscape planning and so have the opportunities that digital technologies offer to planning (Potts, 2020). The importance of communication and its needs in various phases of planning such as in the goal setting, visioning, plan making, evaluation and the plan finalization phases (see e.g. Sharifi et al., 2002; Staffans

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https://doi.org/10.1016/j.landurbplan.2023.104716
Received 30 June 2022; Received in revised form 18 December 2022; Accepted 11 February 2023
Available online 23 February 2023

et al., 2020) has increased in parallel with the overall digitalisation of urban environment and the growing interest in various digital tools (Staffans, Kahila-Tani, Geertman, et al., 2020). In particular, digital three dimensional (3D) tools and approaches supporting communicative planning have been developing fast in the past two decades (Billger et al., 2017; Gill & Lange, 2015; Lovett et al., 2015) and attracted attention in their capacity to support citizen and stakeholder participation and collaboration (Bouzguenda et al., 2021). This interest follows the view that digital visualisations have power to offer new insights through visual representation of knowledge, geovisual analytics of vast amounts of data available in our societies and facilitating collaboration among various stakeholders in order to develop solutions to real-life problems (MacEachren 2001; MacEachren et al. 2004; McCormick et al. 1987). With advances in technology, accessible and interactive visualisation solutions have been developed with the aim of catering for the different user groups and their perceptual and cognitive processes (Andrienko et al., 2011; MacEachren et al. 2004). In recent years, reality-based 3D geovisualisations and 3D city models have been applied to facilitate participation in planning (Biljecki et al., 2015; Jaalama et al., 2021; Virtanen et al., 2015), along with the visions of digital twins, which provide a digital mirror representation of the prevailing physical environment and interact with it in order to provide real-time data of it for planners and stakeholders (Batty, 2018; Ketzler et al., 2020; Tao et al., 2019). Currently various 3D visualisations are applied as communicative tools in architecture, landscape architecture, and land use, landscape and environmental planning at different stages of planning processes (Lovett et al., 2015; Portman et al., 2015).

3D visualisations used with citizens and other stakeholders in the context of urban and landscape planning are ultimately aimed at enhancing the substantive, instrumental and normative values of public participation (Fiorino, 1990; IAP2, 2014). 3D visualisations are, for example, envisioned to support the substantive and instrumental values through shared language and, consequently, communication between planners and stakeholders, integration of experience-based and professional knowledge, and sensitivity to and awareness of the planning issues for high quality and more acceptable decisions (Hruby et al., 2019; Lovett et al., 2015; Orland et al., 2001). They are also aimed to attract public interest in planning processes in order to fulfil the normative goal of wider democratic participation (Engman, 2016). Each planning phase, however, calls for appropriate visualisations depending on the tasks at hand (Billger et al., 2017; Staffans, Kahila-Tani, Geertman, et al., 2020). In particular, an empirical study by Wissen Hayek (2011) highlights that different 3D visualisations facilitate participatory planning tasks differently. For example, abstract (non-realistic looking) 3D visualisations helped participants to focus on various attribute or spatial data aspects when analysing the planning area thus fostering substantive value of the participation, while realistic looking 3D visualisations were useful in better understanding the causes and effects of developments and potentially enhancing acceptability of the decisions, i.e. instrumental value.

Participatory and collaborative planning practices have their roots in communicative planning theory that emphasises, in addition to communication, shared knowledge building, mutual learning, and inclusiveness (e.g., Forester, 1999; Healey, 2006). A planning process consists of a sequence of communicative actions that involve both professionals and lay people (Staffans, Kahila-Tani, Geertman, et al., 2020). Staffans, Kahila-Tani, Geertman, et al. (2020) emphasise the changing knowledge needs and the different types of communication within the planning process. At times, there is a need to diverge the knowledge base, i.e., to engage a large and diverse group of participants to gain more knowledge and give space for various voices and new thinking. At other times a need to converge the knowledge exists, where participants discuss the value of the diverse knowledge claims and refine, negotiate and choose ideas for further elaboration. It is also essential to recognise the differences in communication between participation and collaboration. Participation refers to working and communicating with a broad public and collaboration means working in small, selected groups (Innes & Booher, 2007; Staffans, Kahila-Tani, Geertman, et al., 2020). Thus, the needs for communication methods and tools vary during the planning process and in terms of 3D visualisations, it would be important to consider what communicative actions they are meant to promote.

The development of 3D visualisations is prominent both within and outside of academia in a variety of fields, including information and communication technology, computer science, urban and environmental planning, cultural heritage and education (Billger et al., 2017). 3D visualisations can be divided into non-georeferenced visualisations, such as virtual worlds on game engines, and 3D geovisualisations with geospatial reference representing the real world, parts of the real world or other data with a spatial reference (Bleisch, 2012). Examples of these are Google Earth, 3D city models, 360 panoramic street views, elevation models with topographic data and photogrammetry advanced 3D models. The technological production process and platforms as well as the level of real-world realism and immersiveness differ greatly. The methods for generating 3D visualisations vary from manual processing to semi-automated means. The level of realism in 3D visualisations vary from non-reality-based or non-realistic-looking visualisations (Döllner, 2007) to realistic-looking or photorealistic visualisations (Julin et al., 2019). Furthermore, 3D visualisations are presented with varying levels of immersiveness. Head-mounted displays (HMD), stereo displays and Cave Automatic Virtual Environments (CAVE) are usually considered the strongest for generating a sense of presence (Çöltekin et al., 2016), while augmented reality (AR) based solutions extend the experience of the tangible reality (Li & Fan, 2014). However, some 3D visualisations are tailored for watching on 2D screens, where the immersiveness is minimal (Celio et al., 2015; Dahlhaus et al., 2016).

Promoting communicative planning with citizens and other stakeholders exerts certain requirements for the 3D visualisations. The emphasis in the technical solution and user interface development shifts particularly to the needs and perspective of the lay end user and the interaction the visualisation enables; be it the interaction between the user and the technology, i.e. human–computer interaction (Dix et al., 2004), or communication between users. Common considerations in designing digital tools for participation and collaboration are i.a. accessibility, usability and meaningfulness to the end user (Kahila-Tani, 2015; Zhang et al., 2019). Lovett et al. (2015) list several aspects to consider when using and developing 3D visualisations: the setting it is being applied to, the visualisation content (e.g., the form of presentation, including interactivity and immersion) and the overall credibility, saliency and legitimacy of the visualisation. Furthermore, 3D visualisations require a carefully considered balance between abstraction and realism (Voinov et al., 2018), while the level of realism has been shown to be a task and audience dependent factor (Lovett et al., 2015). Regarding immersion, it has been suggested that the more immersive the visualisation and the communicative process are, the more effectively they engage stakeholders to discuss the planning decisions and implications for their environment (Gordon et al., 2011). These requirements ought to be considered in relation to the objectives given to the engagement, e.g., scenario feedback collection versus facilitation of collaborative planning (Lovett et al., 2015).

The discussion about the usability and potential of 3D visualisations is active among planners, municipalities, private sector developers and civil society actors who develop and adopt these solutions into practice. Discussions are found in professional journals, in industry blogs and on company websites. However, the communication culture and the relationship with evidence-based knowledge in the non-academic forums differs from that prevalent in the academic community (Billger et al., 2017; EBDJ, 2015) where, for example, the evaluation rigour, depth and basis on theories of communicative planning are more emphasised. In building evidence of the usability and potential of 3D visualisations in planning, the transparency and systematic reporting of methodologies and knowledge production are important. Academic research exists on how useful 3D visualisations are for planners and professionals (e.g., Batty & Hudson-smith, 2014; Herbert & Chen, 2015; Ho et al., 2015; Serginson et al., 2013), but fewer focus on their application contexts and usefulness, i.e., their utility and usability (Nielsen, 1994), for participatory and collaborative planning. Usability evaluations of 3D visualisations also apply varying aspects including the effectiveness, efficiency and satisfaction in achieving specific goals or the appropriateness of the solutions offered (Bleisch, 2012). Calls for better replicability and reproducibility of research in geospatial sciences have been made due to the demands of evidence-based decision making (Kedron et al., 2021). This requires thorough documentation of the conceptual and analytical choices made during a study be they related to the 3D technologies applied, stakeholders engaged, the planning process or usability evaluation.

There are no reviews or systematic mapping of literature, to our knowledge, that solely focus on studies that apply 3D visualisations in communicative planning. Namely either reviews that investigate the available evidence of usability of 3D visualisations for communicative planning or systematic mapping of research that documents the scope and gaps in current research on 3D visualisation applications and usability in communicative planning (Collaboration for Environmental Evidence, 2013; Kitchenham et al., 2010). Billger et al. (2017) conducted a literature review on the prevalence, usability assessments and challenges associated with different visualisation tools, including a few 3D visualisation applications. According to the review, most usability studies are experimental and prototype studies, while real planning process and implementation studies are rare. Nasr-Azadani et al. (2022) looked at studies on various visualization types from 2D maps to immersive 3D technologies and the level of public participation they had been used for in natural resource planning. Biljecki et al. (2015) reviewed the use of 3D visualisations across multiple domains, among which urban planning and communication of information to citizens feature as use case examples. Çöltekin et al. (2016) reviewed 3D geovisualisation literature and identified arguments for and against their use in terms of when, in what kind of form and for whom. Çöltekin et al. (2019) summarise the evidence in a special issue of empirical case studies of virtual and augmented reality (VR and AR) in various domains and highlight the need to further study the interactivity of these methods. Finally, in a review by Lovett et al. (2015), the most effective use of 3D visualisations for landscape planning is discussed and future research needs are suggested. The authors remark that today the technical advances of these visualisations outstrip our current understanding of their best usage in practical planning contexts and that their effectiveness should be more comprehensively evaluated.

In this study, we review recent academic literature on case studies of 3D visualisations that have been utilised or developed to support participation and collaboration of citizens and or other stakeholders in urban and landscape planning. We acknowledge the vast amount.

of 3D visualization applications and the development of the field outside academia as crucial in their own right. However, we opt to focus on academic literature and knowledge creation, which contribute to the development of methodologies and theoretical basis for the communicative use of 3D technologies. By collating the research literature, we gain understanding on the characteristics of these particular 3D visualisations reported in the scholarly work and the link they have to planning practice. Particularly, the aim is to determine the empirical knowledge base that scientific literature currently offers for understanding the usability of 3D visualisations in communicative planning. The specific questions to address are:

1. In what kind of contexts have 3D visualisations been applied related to communicative urban and landscape planning?
2. What technological solutions are used for the visualisations and human–computer interaction?
3. What kind of communicative planning do 3D visualisations facilitate and for which kinds of planning purposes are they developed? And finally,
4. What type of usability evaluations are prevalent to understand usability of the 3D visualisations in communicative planning and how are these evaluations conducted?

In the discussion, we reflect on the limitations of the existing scientific literature for informing a systematic evaluation of the 3D visualisations' usability in communicative urban and landscape planning.

2. Systematic mapping of research

2.1. Literature search

Systematic literature reviews assist in making sense of large amounts of data, find answers to particular questions, identify what works and what does not, and map out areas of uncertainty showing where more research is needed (Petticrew & Roberts, 2006: 2). Systematic reviews are common in the fields of environmental science and the nexus of urban planning and human health and wellbeing (Barros et al., 2019; Labib et al., 2020; Moghadam & Rafieian, 2019; Stone et al., 2019). They have recently been applied, for example, to analyse the extent to which participatory digital platforms are used in urban planning (Falco & Kleinhans, 2018), how crowdsourcing is utilised in solving urban problems (Chaves et al., 2019), and how smart city innovations affect urban policing and safety (Laufs et al., 2020). In the field of built environment planning, systematic reviews have been identified as a way to achieve evidence-based practice (Hall et al., 2017).

Systematic mapping is a form of systematic literature review (Collaboration for Environmental Evidence, 2013; Kitchenham et al., 2010) that we apply in this article. In a systematic mapping, the aim is to identify and categorize the existing research in a field or on a topic and describe the extent of that research such as sub-topics addressed, empirical methods used, and the sub-topics that have sufficient or insufficient empirical studies for a more detailed systematic review of evidence (Fagerholm et al., 2016; Hall et al., 2017; Kitchenham et al., 2010). In a systematic mapping research is categorized and aggregated based on specific variables of interest. Departing from basic systematic mapping procedure, we place emphasis on the quality and relevance of the publication (e.g. availability of information on the case study characteristics) and as such follow the systematic review tradition, where the rigour of evidence and relevance of the reviewed studies are essential (Kitchenham et al., 2010). We apply the established guidelines for conducting and reporting systematic literature reviews (Collaboration for Environmental Evidence, 2013; Moher et al., 2015; Pullin & Knight, 2009; Pullin & Stewart, 2006).

In the mapping, we include case studies from the fields of urban and landscape planning. We omit transportation planning and building design and architecture due to differences in planning contexts and issues to consider (e.g., detailed scale of planning, relevant questions, needed information, and level of details in the 3D model). We created a review protocol, reported in a separate document, to guide the systematic mapping process (Eilola et al., 2021). The protocol was reviewed by an informatician of the Turku University Library. Three principal electronic academic databases were used in the publication search; these included the Web of Science Core collection (WoS), Scopus and Open grey repository (https://www.opengrey.eu). Google Scholar was used as a supplementary literature source, because its search system and curation do not meet the standards of curated bibliographic databases (Gusenbauer & Haddaway, 2020). The publication search entailed a combination of three search strings in English, namely:

1. 3D visualisation and related terminology (such as 3D geovisualisation, 3D model, digital earth, 3D decision support system and 3D GIS);
2. urban and landscape planning-related definitions, including land use and environmental planning and design, and

3. various related concepts for participatory and collaborative engagement such as people-centred, community-based and communicative (complete search strings in appendix A).

A scoping exercise was performed to iteratively test and improve the effectiveness of the search terms and strings in capturing a wide variety of relevant use cases of 3D visualisations in literature. We acknowledge that some relevant publications might not have been captured by the search strings, especially due to disciplinary differences in terminologies. We omitted science domains related to medicine, material science, mathematics, physics and biology in the database searches to reduce the number of search results. Due to interest in the recent technological development and the desire to review the state-of-the-art and go beyond the earlier published reviews (Biljecki et al., 2015; Billger et al., 2017; Çöltekin et al., 2016, 2019; Lovett et al., 2015), we used a cut-out year of which over half of the found items had been published in Scopus, which was the largest principal search database we used. Thus, our dataset covers the years from 2013 to mid-2020.

The initial publication searches were conducted on May 28 and June 6, 2020 and resulted in a total of 1841 publication records after deduplication was performed in Mendeley and subsequently in Excel (Fig. 1). The publications were stored as title, abstract and publication detail information in an Excel database. We then applied the following inclusion criteria and selected from the records those studies that:

1. Employ a 3D visualisation that supports communication in relation to an urban and landscape planning process.
2. Test, pilot or apply in real-life the 3D visualisation with citizens or stakeholders as a tool for communicative planning. As stakeholders we define, e.g., different sectoral administrations, civil society organisations, and people in an expert role. We define the concepts of participatory and collaborative planning broadly and refer to any form of citizen and stakeholder engagement in urban and landscape planning regardless of the planning process phase.
3. Document enough information to determine the relevance of the study following the above criteria and information on the majority of the reviewed variables in the publication that allow us to answer the research questions of the review (description of variables in section 2.2 and Appendix B).

The records were selected through a three-phase filtering process (Pullin & Stewart, 2006). The aforementioned inclusion criteria were applied in the first phase to filter the 1841 records based on the title only; in the second phase records were filtered based on the abstract (or the introduction section or equivalent). In the third phase filtering was performed by viewing the remaining 136 records at full text content. This resulted in 39 records to form our review database. Records were included in the next phase of the filtering process in cases of doubt, when the information provided in the title or abstract was not enough to determine the relevance of the record in relation to the inclusion criteria. In six cases where a study and its results were covered in several publications, the one publication, which documented most comprehensively information about the 3D technology, its application and usability evaluation was included in the review database and in the analysis. These other publications covering the same study were screened for details of the study, if the information was not sufficiently provided in the reviewed publication.

Three authors (S.E., K.J. and N.F.) independently conducted the first filtering phases of title and abstract on a random subsample of 10 % of the records to check for consistency of application of the inclusion criteria (Pullin & Stewart, 2006). An average Kappa value was calculated as 0.458 ($p = 0.000$), which indicated disagreement between the reviewers (Cohen, 1960: < 0.5). The authors then discussed the discrepancies and clarified the interpretation of the inclusion criteria. All remaining unclear records were examined together by the authors.

In the end, we conducted a refinement to our database searches. We added terms related to decision support systems and gaming software to our 3D visualisation related search string based on reviewer comments. We also tested whether our initial search had left out relevant items due to the selected science domains and thus included in the search material science, mathematics and physics-related science domains. We ran the refined searches in Scopus and WoS on March 10, 2022 and used the

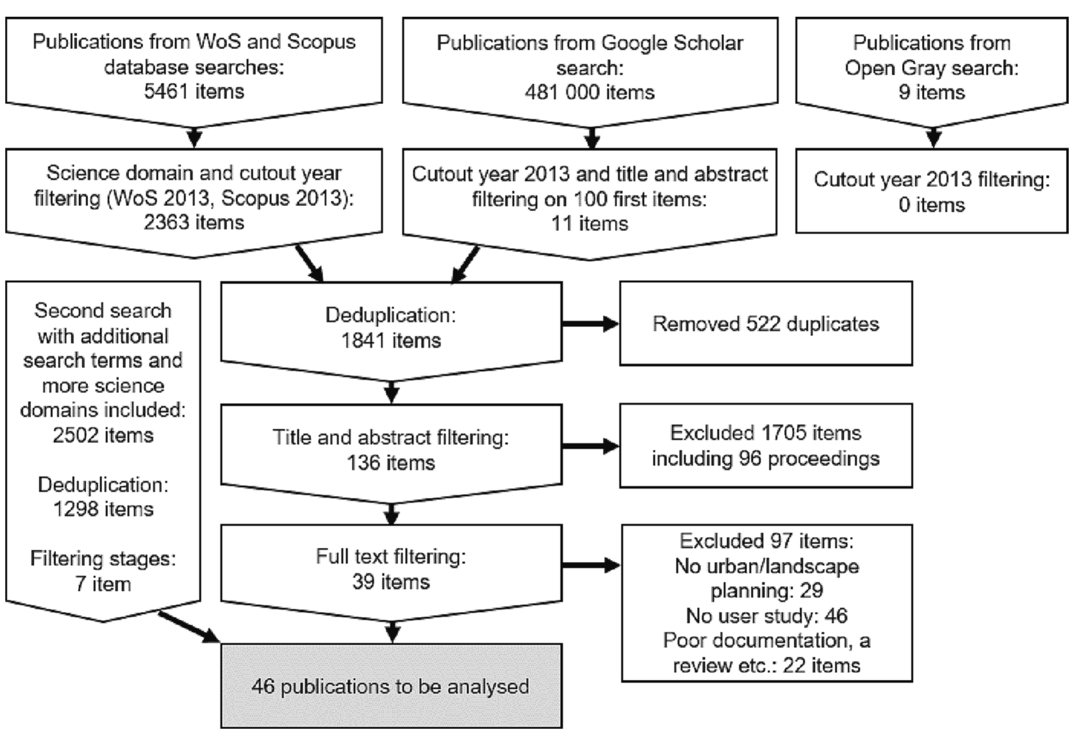


Fig. 1. Database search and literature filtering process. The graph shows the number of publications remaining at each phase of filtering. The second database search and filtering process is described as a separate process.

original time range. After the filtering (by S.E. and K.J) we added seven publications into our dataset - one captured through the added science domains and six by the new search terms. Together with the publications found in the initial searches this totalled to 46 publications to be considered in the review.

2.2. Data extraction and analysis

We developed a matrix with variables to extract, characterize and analyse the extracted data from the literature. The matrix included variables following our research questions and included several variables under each of the following themes:

1. publication details,
2. application context,
3. characteristics of the 3D technology,
4. characteristics of the participation and collaboration exercise
5. characteristics of the possible usability evaluations (see full list of variables in Appendix B).

Publication details include for example year of publication, journal name and disciplines of authors' affiliations. Application context includes for example information about the case study site and its geographical scale and the end and test users of the 3D visualisation. To synthesise the field of 3D visualisations in participatory planning we categorised the reviewed publications based on the novelty the publications claimed to provide. We identified the highlighted novelty of each publication by content analysis of the results, discussion and the conclusions sections of the publications. Three novelty categories were formed deductively based on this and the case study context characteristics by investigating the highlighted outcomes. These categories indicate the main aim and contribution of each publication to the evidence base of 3D visualisations' potential use in communicative planning. The data-derived categories are 1) technical studies highlighting a novel technical solution, such as prototype, work pipeline or demonstration; 2) user experience studies highlighting testing or piloting with users and evaluation of usability and user experience; and, 3) planning studies highlighting planning implications, including planning-related inquiries and reporting, even if not presenting a real-life planning case. Some papers were identified to present equal novelty in more than one of these categories.

The characteristics of the applied 3D technology were investigated by for example categorising the reported systems for processing, developing and viewing the content, the data sources for the visualisation, the display for viewing and observed visual realism. The characteristics of the participation and collaboration exercise included for instance the purpose of using the 3D visualisation for participation or collaboration and the medium used for communication between people. Moreover, we utilised the theoretical schema by Staffans, Kahila-Tani, Geertman, et al. (2020) and looked at the two variables that characterise participatory and collaborative planning methods: knowledge needs (i.e., diverging or converging knowledge) and mode of participant engagement (i.e., participation or collaboration) in planning processes. We took note of the reporting of a usability evaluation of the 3D visualizations in the publications and categorized the research methods used in each evaluation based on common categories of usability evaluation methods: expert-based methods, participant-based methods (i.e., "user testing") and data analytics (Benyon, 2019). Expert-based methods are evaluations in which a usability expert evaluates a design or user interface analytically (e.g. heuristic evaluation). Participant-based methods refer to empirical testing with actual users to examine how they use the interface to complete tasks and to gather direct feedback from the users. Data analytics entail evaluation of the usability on the basis of computational data collected from its use. (Benyon, 2019).

We added the data from each publication to the matrix either as predefined categories or as text citations (Appendix B). We also added a column in the matrix for our comments regarding the publication relevance and quality. The data were extracted and analysed through content analysis (Yin, 2011). Predefined variable categorisations were identified from the publications using directed content analysis and analysed applying descriptive statistics. The variables with text citations were analysed using conventional content analysis deriving the categories from the data. We used a qualitative data analysis software, NVivo 12, to analyse variables that were based on larger narrative text contents and Excel for descriptive statistics. The data extraction and analysis involved significant interpretation of the content and its meanings; hence, they were done iteratively and in collaboration with different combinations of the authors of the review. The interpretations are not therefore merely interpretations of one single author. Some publications lacked enough information on certain variables. In the following results section, the number of publications or case studies that exhibit certain variable characteristics are reported together with the n-values, which indicate the total number of publications that included the required information.

3. Results

3.1. Publication details

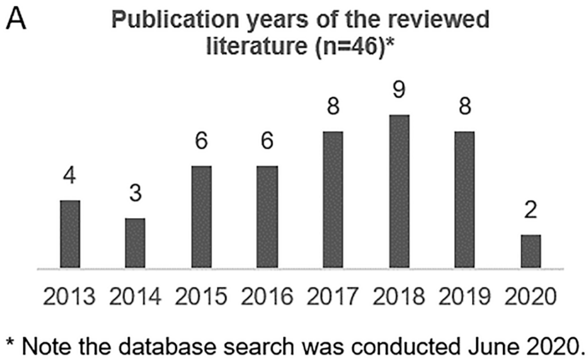
Among the 46 reviewed publications were 33 journal articles (original research papers), 11 conference papers and two book chapters (Appendix C). The most common journals were Landscape and Urban Planning (4), Sustainability (3) and ISPRS International Journal of Geo-information (2). Journals that feature only once come from similar fields including planning and landscape science, sustainability science and digital technology and (geo)informatics. An increase is seen in the number of publications since 2013 (Fig. 2A). The author affiliations link most commonly to the following disciplines: environmental sciences and computer and data sciences (Fig. 2B). Research funders were mostly academic (12), national foundations or programmes (9) and public sector (6), which was usually co-funding the research with other funders. A few publications reported funding from international programmes and the private sector. Eighteen publications had no mention of the funding source.

3.2. Application contexts of the 3D visualisations

Most of the studies (37, n = 42) are from Europe, North America and Australia (Fig. 3A). Most publications report a case study from one single site (38, n = 45); only four publications report that the 3D visualisation has been used in more than two sites (in 3, 4, 7 and 8 sites respectively; (Fisher et al., 2019; Scholten et al., 2017; Wissen Hayek et al., 2019; Yu et al., 2018). Urban planning (14, n = 46) and urban design (9) are the most common planning sectors in which the 3D visualisations have been used, followed by land use planning (6) and environmental management (6) (Fig. 3B). The most common administrative or geographical scales of the 3D visualisation are particularly large areas such as a forest or a water catchment (11, n = 48), a neighbourhood (10) and an urban lot for particular functions within a neighbourhood (9) (Fig. 3C). Over half of the publications reported the 3D visualisations addressing both the current situation and the future scenario (28, n = 46) (Fig. 3D). Future scenarios were the sole focus in 12 publications and the current situation in three publications. In two publications, the 3D visualisation was a hypothetical situation that the participants created (Kent et al., 2019; Tabrizian et al., 2017), and one publication illustrated a 3D historical reconstruction of a city (Morrison & Rubin, 2015).

The highlighted novelty in most publications was either the participatory planning implications of the 3D visualisations (15, n = 46) or the user experience and usability evaluation (15) (Fig. 3E). Seven publications highlighted the new technical solution and its planning implications – four of them additionally focused on the educational benefits of the 3D visualisation for active citizenship among youth (Magnussen &

A



B **Disciplines of affiliated authors (n=42)**

	No.	%
Environmental sciences	10	23.8
Computer and data science	10	23.8
GIS and spatial sciences	8	19.0
Urban planning	8	19.0
Engineering (miscellaneous)	8	19.0
Landscape planning	7	16.7
Architecture	6	14.3
Health sciences and psychology	4	9.5
Geography	3	7.1
Innovation science	3	7.1
Social sciences	3	7.1
Forest sciences and agriculture	2	4.8
Urban systems and environment	2	4.8
Climate change	1	2.4
Geodesign	1	2.4

Fig. 2. Distribution of publication years of the papers (A) and disciplines of the affiliated authors (B).

Elming, 2017; Nishita & Terada, 2019; Rexhepi et al., 2018; Scholten et al., 2017). Six publications highlighted primarily the technical solution with planning and user experience aspects in a minor role as the novelty. Three publications exhibited novelty in both planning implications and usability evaluation (Fisher et al., 2019; Schroth et al., 2015; Van Leeuwen et al., 2018).

Academic actors were involved in the 3D visualisation development in all the publications, in which the visualisation developers were explicitly mentioned (n = 41). Researchers were collaborating with public, private and or third sector actors in different combinations in 11 publications. End users were reportedly involved in the development only in five publications (n = 38). End users were defined in this review as people who were envisioned by the authors as those who will use the visualisation to involve others or who will use it to themselves participate independently or take part in collaborative activities. Citizens were the most commonly mentioned end-user group (29, n = 41) followed by planners (18) and public sector (11) (Fig. 4A). In nearly half of the publications (20, n = 46), both citizens and expert stakeholders with a particular professional role in relation to the planning area or topic were envisioned together as end-users of the 3D visualisation.

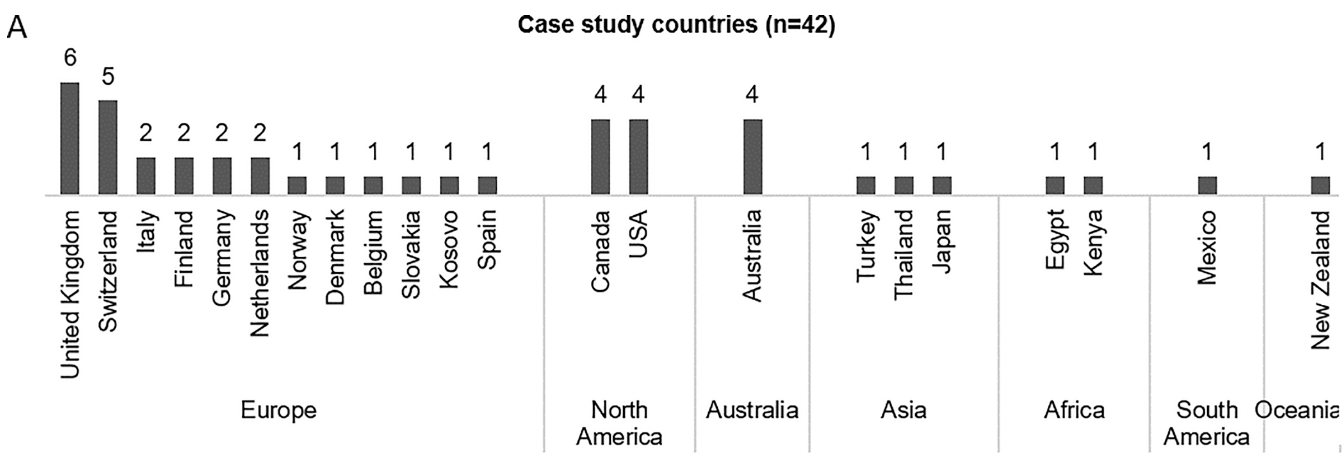
The 3D visualisation had been piloted with users in relation to a simulated real-life-like planning case in approximately half of the publications (25, n = 46) (Fig. 4B). The visualisation had been tested with non-end users, such as university students, or without a simulated real-life-like planning case in 17 publications. Only in four publications, the visualisation had been used with end users in real-life planning related processes and, thus, had potential impact on the planning decisions (Dahlhaus et al., 2016; Dembski et al., 2020; Konisranukul & Tuaycharoen, 2013; Van Leeuwen et al., 2018). The number of test users, namely the people who had been involved in the case studies as users of the technology, varied markedly among the case studies (Fig. 4C) but the majority of cases reported more than 30 test users. The highest number of test users in a case study was 1378 users in a real-life planning related case (Van Leeuwen et al., 2018). The test users represented all or almost all of the envisioned end-user groups of the visualisation in 32 publications (n = 40 [the number of publications in which both end and test users were explicitly mentioned]). No end-user groups were among the test users in eight publications.

In addition to disclosing the test user's role, such as a citizen, expert or student, their age (47.8 %, n = 46) or gender (45.7 %) was reported in nearly half of the publications (Fig. 4D). Other background variables, such as test users' familiarity with the planning area or previous experience with 3D technology, were less commonly reported. In 19 publications the profession or citizen status were the only background information provided. The citizen category was usually mentioned to represent the general public or residents, however, two publications targeted marginalized groups or contexts in particular; indigenous community members in Fisher et al. (2019) and a deprived urban neighbourhood in Magnussen & Elming (2017). It is worth noting that the background variables were not necessarily used to analyse the user's performance or perception of the 3D visualization but to simply characterize the test user sample.

3.3. Characteristics of the 3D technology and user interface

The terminology used for the 3D visualisations was unique and diverse among the publications and included, for example, (virtual) landscape (design) model, (an interactive web-based) 3D environment, land use decision model, (interactive) 3D visualisation, (web application with) 3D scene, 3D groundwater visualisation, urban digital twin, geosimulation, participatory modeling, 3D projection-augmented landscape modeling, (participatory) 3D GIS, realistic 3D, BIM, 3D point cloud, 3D representation, virtual world, landscape visualisation, 3D rendering, fly-through, 3D (virtual) city model, 3D (computer/architectural/virtual) model (in urban and community planning), geovisualisation, 3D city web geoportal, virtual reality simulation, landscape visualisation, immersive visualisation, 3D reconstruction, (immersive) virtual reality (based platform), virtual experience, (3D/immersive) virtual environment, virtual globe, 3D decision support system, and AR Sandbox.

Numerous different platforms were utilised for the 3D visualisation development and viewing. 3D modelling software was the most common platform for this (27, n = 46), while a game or game engine was applied in 15 and GIS-based solutions in 14 cases (Fig. 5A). Some publications reported the use of software libraries (8), a raster graphics editor (6) and computer-aided design (3). Twenty-four other systems and platforms mentioned included, for example, self-built platforms and two platforms that were unidentifiable based on the information available. Appendix D presents a detailed list of the applied platforms. The data sources for 3D



B Planning or management sector (n=46)

	No.	%
Urban planning	14	30.4
Urban design	9	19.6
Land use planning	7	15.2
Environmental management	6	13.0
Landscape planning	5	10.9
Landscape design	4	8.7
Urban studies	1	2.2
Landscape visioning	1	2.2

C Administrative or geographical scale (n=46)

	No.	%
Particular larger area not an admin region	11	23.9
Neighborhood	10	21.7
Urban lot for particular functions	9	19.6
Region	5	10.9
City or town	6	13.0
Street, river side, bridge	4	8.7
Landscape scene	2	4.3
Building and its shadow effect	1	2.2

D Visualized situation (n=46)

	No.	%
Current situation and future scenarios	28	60.9
Future scenario	12	26.1
Current situation	3	6.5
Hypothetical situation	2	4.3
Historical reconstruction	1	2.2

E Highlighted novelty of the publication (n=46)

	No.	%
Participatory planning implications	15	32.6
User experience and usability evaluation	15	32.6
Tecnical solution and its planning implications	7	15.2
Tecnical solution	6	13.0
Planning implications and usability evaluation	3	6.5

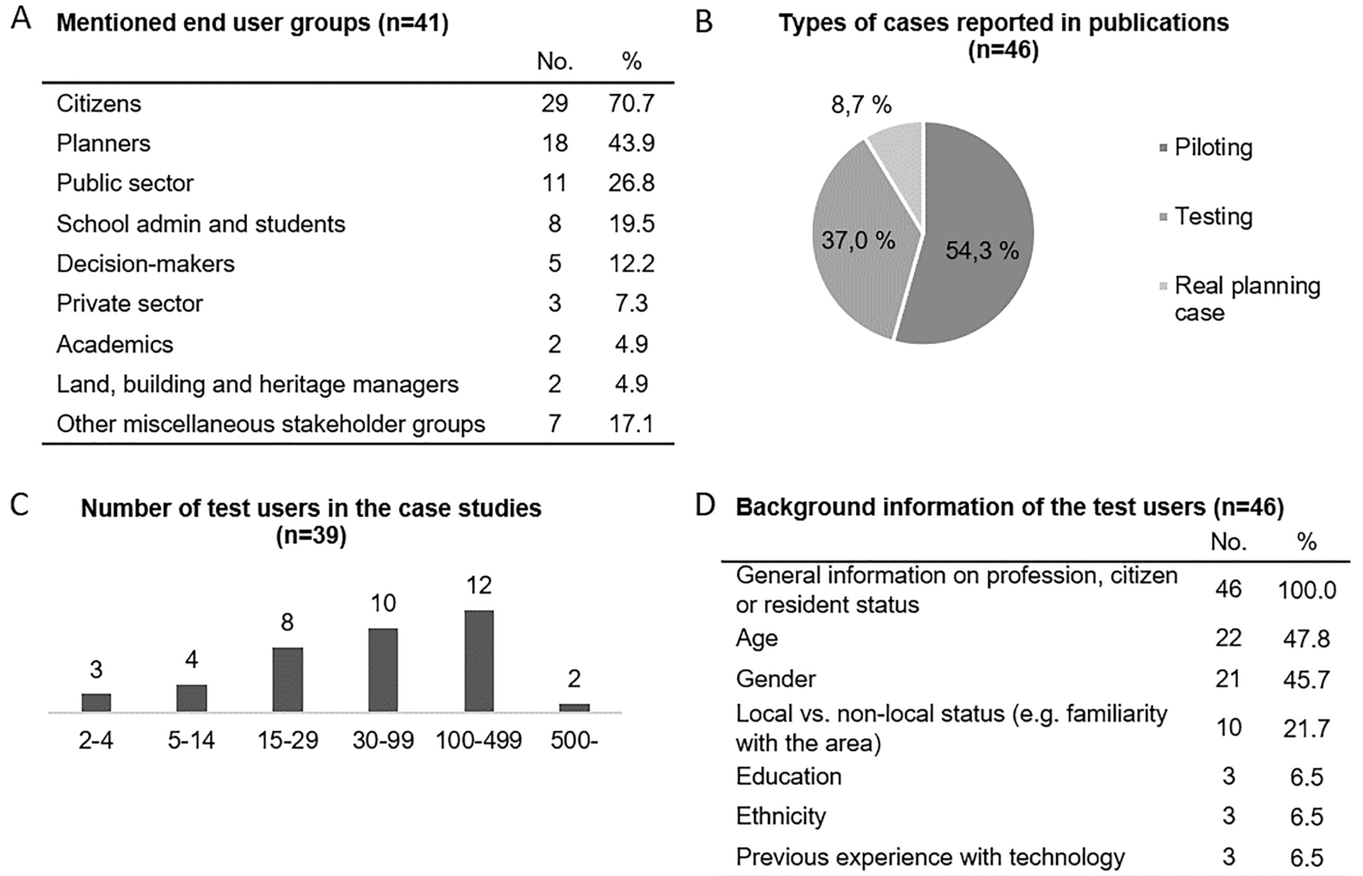
Fig. 3. Distribution of case study countries (A), targeted planning and management sector (B), administrative or geographic scale (C) and the visualised situation (D) in the 3D visualisations as well as the highlighted novelty of the publication (E).

visualisations were reported in 37 publications. They varied from 2D mapping and related geospatial data (20) to existing city and 3D models, including Google Earth (16) (Fig. 5B). Ten publications reported the use of sensor and photogrammetric data and nine the use of descriptive data, such as statistical data. Almost half of the publications (23) reported multiple data sources.

The most utilised display type for the 3D visualisations was a 2D screen (31, n = 43) (Fig. 5C). It was utilised as the sole medium in over half (26) of the cases and together with other display types in five cases. Head-mounted display was the second most common (11) and utilised together with other displays in six cases. CAVE and AR sandbox were each utilised in two cases (Afrooz et al., 2018; Dembski et al., 2020; Fisher et al., 2019; Polys et al., 2018). The targeted level of realism in the 3D visualisations was realistic looking in 18 publications and photo-realistic in five publications (n = 44). Six publications utilised a non-realistic visualisation (see, e.g., Menconi & Grohmann, 2018). Fifteen publications utilised both realistic and non-realistic visualisations. Real-time 3D technology, that is, interactive rendering of 3D images, was utilised in 32 publications (n = 44). Pre-rendered static images or videos (3D renderings) were used in 12 publications.

The access for participants to engage with the 3D visualisation varied greatly among the case studies. The most common way for a participant to access the visualisation in individual exercises was online using their own device such as computer, laptop or tablet (10, n = 35) followed by a special hardware such as VR headset or a tactile 3D model (Fig. 5D) provided by the researchers or planners. In collaborative group exercises, most commonly a non-special hardware, such as a regular computer or projector provided by the researchers or planners, was used (7). In three cases a combination of special and non-special hardware was used. A special hardware was used in two publications, in which both individual and group exercises were carried out (Dembski et al., 2020; Newell et al., 2017).

The most common functions for participants to use in the 3D visualisation interface were choosing and adjusting the viewing perspective and/or data layers shown to them; this was enabled in 28 cases (n = 43) (Fig. 5E). Participants could choose to view certain predefined simulated



A **Mentioned end user groups (n=41)**

	No.	%
Citizens	29	70.7
Planners	18	43.9
Public sector	11	26.8
School admin and students	8	19.5
Decision-makers	5	12.2
Private sector	3	7.3
Academics	2	4.9
Land, building and heritage managers	2	4.9
Other miscellaneous stakeholder groups	7	17.1

D **Background information of the test users (n=46)**

	No.	%
General information on profession, citizen or resident status	46	100.0
Age	22	47.8
Gender	21	45.7
Local vs. non-local status (e.g. familiarity with the area)	10	21.7
Education	3	6.5
Ethnicity	3	6.5
Previous experience with technology	3	6.5

Fig. 4. Mentioned end-user groups (A), types of cases studies (B), number of test users of the 3D visualisations (C), and reported background information of the test users (D).

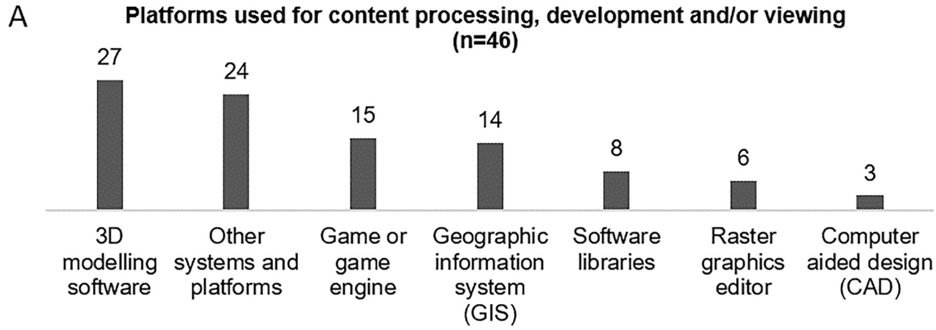
parameters of the 3D visualisation such as different water levels simulated by flood model, airflow simulation and carbon-dioxide absorption rates of trees in nine publications. However, they were only able to view the model from a predefined perspective without any other functionalities in eight publications. These cases were, for example, such that the 3D visualisation was embedded into an online questionnaire in which still images or a walk-through of the 3D visualisation were displayed (Celio et al., 2015). The participants created a digital or non-digital 3D model themselves in 11 cases. In four of these cases they crafted a tangible model which was subsequently digitized, whereas in six cases they crafted it in digital form for example using Minecraft software.

3.4. Characteristics of the participatory and collaborative exercises

The most common mode of participant engagement (see Staffans, Kahila-Tani, Geertman, et al., 2020) was participation (22, n = 45), followed by collaboration (19). Additionally, the engagement in four publications was for informing and increasing understanding among the participants on climate change and flooding impacts in the case study area. The most common type of knowledge need for planning purposes was diverging knowledge (20, n = 37), followed by converging knowledge (12) and the need for both diverging and converging knowledge (5). When the mode of participant engagement and knowledge needs are examined together as communicative actions, the results show that 14 of the 3D visualisations (n = 32) engage the broad stakeholder base in the process (participation) to address the need to open up the planning process to multiple voices (diverging) (Fig. 6A). A much smaller number of 3D visualisations (5) aim to converge the planning information with a broad public. Collaboration was used in six cases to diverge the knowledge base of planning and in seven cases to converge the knowledge and reach shared conclusions. In addition, there were also five cases in which both converging and diverging knowledge were sought in participatory or collaborative exercises using the 3D visualisation.

Better understanding of the planning area and/or design or scenarios (22, n = 46) and collection of feedback from the participants on an existing land use plan or scenario (21) were among the purposes for using the 3D visualisation in almost half of the publications (Fig. 6B). Using the 3D visualisation as a discussion aid tool and for enabling participants to create their own plans or scenarios were also commonly mentioned. The 3D visualisation was used in the visioning phase in three of the four real-life planning related cases, with the purpose of facilitating scenario evaluation. Creating plans or scenarios was done with an application on 2D screen, AR sandbox or a tactile model such as a Lego model, which was then digitized and displayed in HMD (Kent et al., 2019) (Fig. 6B). HMD was used most commonly for collecting feedback on an existing plan or scenario and or for enhancing better understanding. The main mentioned purpose to use CAVE was as a discussion aid tool (Dembski et al., 2020; Polys et al., 2018) and for panoramic projection/screen most common purpose was collection of preferences for plan development or plan feedback (Wang et al., 2016; Wissen Hayek et al., 2019).

The most commonly mentioned forms of data that the case studies collected for land-use planning purposes were a questionnaire or voting contributions separately from the 3D visualisation interface (9, n = 33) or as part of or linked to the visualisation interface itself (8) (Fig. 6C). A model or scenario creation was the output in 11 publications and plan decisions, design choices or scenario selections made by the participants in six publications. Discussion notes or recordings were also captured in six publications and they were the only form of data collection for

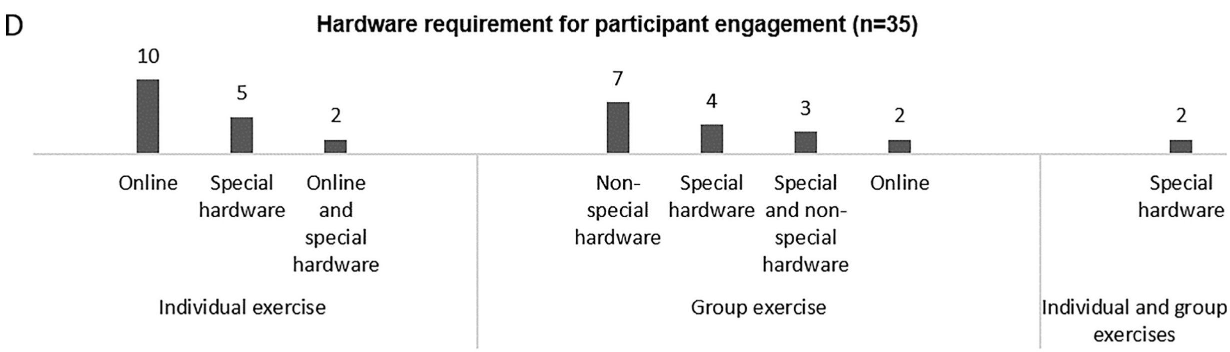


B **3D visualization source data (n=37)**

	No.	%
Map, orthophoto, aerial imagery, and/or elevation map	20	54.1
City or (scenario) 3D model, and/or Google Earth	16	43.2
Laser scanning, photogrammetry, and/or sonar	10	27.0
Descriptive and/or other data	9	24.3
Photographs	6	16.2
Manual 3D visualization, and/or 3D library	5	13.5
Building footprints	4	10.8
BIM	3	8.1
360 photographs	2	5.4
3D prints	1	2.7

C **Display types (n=43)**

	No.	%
2D screen	31	72.1
HMD	11	25.6
CAVE	2	4.7
AR Sandbox	2	4.7
Multi-touch table	1	2.3
3D projection 160 degrees	1	2.3
Panoramic projection	1	2.3
Wide curved 2D screen	1	2.3
Paper	1	2.3

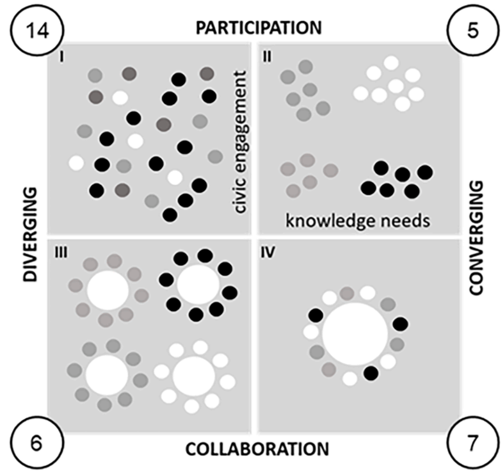


E **Functions for participants to use in the application interface (n=43)**

	No.	%
View the model and change the viewing perspective or info shown oneself	28	65.1
Design a model in digital form, as sandbox or other form	11	25.6
View different parameters of the model or scenarios	10	23.3
View the model but can not change the perspective or shown info oneself (video or predefined walk through)	8	18.6
Answer questionnaire or other feedback giving like voting	8	18.6
Add own data and objects	3	7.0
Add predefined objects	3	7.0
Explore the model by several different ways	2	4.7
Discussion forum	2	4.7
Be an avatar in the model	1	2.3
View other users' opinions	1	2.3

Fig. 5. Different platforms used for content processing, development and viewing (A), source data for the 3D visualisations (B), display types (C), hardware requirements for participant engagement (D), and functions for participants to use in the visualisation interface (E).

A **Dimensions of communicative actions (adapted from Staffans et al. 2020) (n=32)**



B **Purposes of using the 3D visualization in studied cases (n=46) and per display/tool type (n=43)**

	No.	%	2D screen (31)*	HMD (11)	CAVE (2)	AR Sandbox (2)	Panoramic projection or screen (3)	Tactile model (3)
Better understanding of the planning area, topic, design and or scenarios	22	47.8	16	5	1	1	1	3
Collecting plan, design, scenario evaluations or feedback	21	45.7	13	8			1	3
Discussion aid tool	15	32.6	12	4	2	1		1
Plan, design, scenario building or creation	11	23.9	7	2		2		3
Collecting preferences for plan development	8	17.4	5	2			2	
Wide stakeholder involvement	3	6.5	1	1		1		1
Studying perceptions on audio-visual landscape	3	6.5		3				

* In brackets, in how many of the case studies a display/tool type was used in total

C **Form of collected data for planning purposes (n=33)**

	No.	%
Model or scenario creation	11	33.3
Separate questionnaire or voting	9	27.3
Digital questionnaire or voting linked to the application	8	24.2
Discussion notes or recording	6	18.2
Plan decisions, design choices or scenario selection	6	18.2
Interview answers	2	6.1
Cognitive performance measures	1	3.0

D **Type of communication and its medium (n=44)**

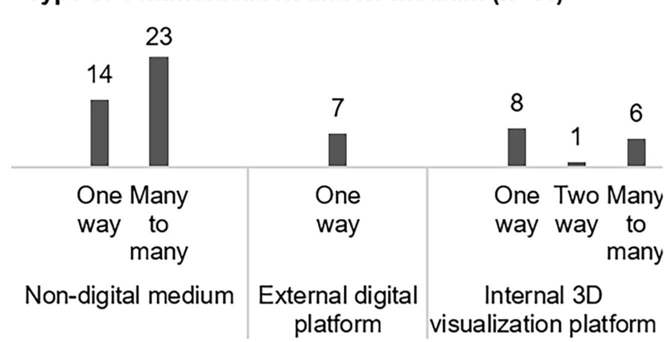


Fig. 6. Dimensions of communicative action (A), purposes of using the visualisation per case studies and per used display or tool type (B), form of collected data for planning purposes (C), and types of communication and its medium (D).

planning purposes in one publication (Lieske et al., 2015). Participant interviews were used in two publications, in one of which it was the only data collection method used (Mell et al., 2016).

Non-digital communication was the most common (37, n = 44) communication that the visualisations facilitated between visualisation developers or planners and participants and among the participants (Fig. 6D). This communication was either one-way or many-to-many communication. One-way communication in the 3D visualisation platform or through an external digital platform separate from the 3D visualisation platform were also common communication types. All three types of communication (i.e., one-way, two-way, many-to-many) were enabled by the 3D visualisation platform itself in one publication (Dambruch & Krämer, 2014). Note that participants placing objects on the 3D-model in the visualisation was considered also as communication. In 25 cases, non-digital communication was the only medium of communication, in six cases, the only medium was the internal 3D visualisation platform, and in five cases, it was the external digital platform. The use of the visualisation was facilitated by the researchers or planners in most of the cases (25, n = 39). The users engaged with the visualisation on their own in the remaining cases.

3.5. Usability evaluations

A usability evaluation of the 3D visualisation had been conducted in half of the publications (24, n = 46). Some types of participant-based methods were used in all these cases. A questionnaire for the test users was the most common (20) method to collect information for participant-based evaluation (Fig. 7A). A questionnaire, interview or discussion to collect user feedback was used as the sole usability evaluation method in 14 cases. In most case studies one (14) or two (7) evaluation methods were used, but there were also four cases applying a combination of several evaluation methods, such as a combination of interviews, a questionnaire, discussion and task-based usability testing (Dahlhaus et al., 2016; Garcia-Martin et al., 2017; Onyimbi et al., 2018; Schroth et al., 2015; Tobias et al., 2016). Ten cases exhibit a comparative study where user experience was studied in similar settings with 3D and 2D visualisations or without a visualization (Atwa et al., 2019; Gill et al., 2013; Hassan et al., 2014; Herbert & Chen, 2015; Onyimbi et al., 2018; Patterson et al., 2017; Schroth et al., 2015; Tobias et al., 2016; Van Leeuwen et al., 2018; Wissen Hayek et al., 2019). Despite the variety of participant-based methods, expert-based methods were nonexistent. Also, data analytics (i.e., logging user's activities by eye tracking or internet analytics (Dahlhaus et al., 2016; Klein et al., 2016), were seldom used. The usability evaluations, including how they were conducted, what were the measured variables and what the findings were, were generally reported fairly briefly or varied greatly in the publications and, thus, cannot be examined either in detail or in a comparative manner. Among the four real-life planning-related cases found in the literature, only in two of them had a usability evaluation been carried out through user feedback collection (Dahlhaus et al., 2016; Dembski et al., 2020).

Thirty-two publications (n = 46) stated clearly or gave enough information to identify the sampling type used to select and recruit test users. The most common sampling types were purposive sampling (15, n = 32) and volunteered participation (11) (Fig. 7B). A random sampling technique was used in two publications (Newell et al., 2017; Van Leeuwen et al., 2018). As said in the chapter 3.2, the number of test users varied greatly in the case studies. In nine cases, where a usability evaluation was carried out, the sample size was over 30 test users. The sample size was very small (i.e., 2–4 users) in two cases, and it is evident that the evaluation results cannot represent all the intended end-user groups. Another shortcoming was the fact that the test users did not represent the actual intended end users in seven of the cases when an evaluation was conducted, e.g., urban planning experts or students can only limitedly test and evaluate a tool intended for citizens.

4. Discussion

4.1. 3D visualisations for communicative planning reported in academic literature

In this systematic mapping of academic literature between 2013 and mid-2020, we examined the scope of scholarly work from 46 scientific publications published, which report case studies employing 3D visualisations to support participation and collaboration in urban and landscape planning. The literature exhibits heterogeneity in the contexts, communicative planning situations and purposes as well as technological solutions of the 3D visualisations across academic fields. Such heterogeneity of use has been previously highlighted by, for example, Biljecki et al. (2015) and Çöltekin et al. (2019).

As our focus was on academic literature, it is not surprising that nearly all of the reported cases are researcher-driven. Envisioned end users, such as professionals, public authorities and citizens, were rarely involved in the technology development process. The end users have, however, been identified and mentioned in most cases, thus indicating a practice-oriented aim of developing the 3D visualisations. Nevertheless, these results indicate a research-practice gap in the field, which can hinder the real-life adoption of the applications developed and the academic study findings concluded. In fact, only four of the reviewed studies had been applied in a real-life planning setting. This tells that we yet have very little scientific evidence to evaluate how different 3D visualisations fare in actual urban and landscape planning processes to deliver the envisioned benefits to communicative planning with stakeholders and citizens (cf. Çöltekin et al., 2016; Lovett et al., 2015). Furthermore, many of the real-life participatory planning or pilot cases exhibited less sensitive planning contexts, such as improving an already existing park or a nature area (e.g., Kwon et al., 2019; Van Leeuwen et al., 2018). None of the cases applied 3D visualisation to facilitate reconciliation of multiple conflicting interests. Hence, the questions related to contested land uses and sensitivities that professionals face in real-life planning seem not to be part of the case study designs.

Even though all reviewed studies were published for the purposes of arguing for the usability of the 3D visualisations in communicative planning, the publications differed in their emphasis on the novelty they offer and, subsequently, the depth of reporting and rigour of usability evaluation. The most commonly highlighted novelty was in the user study or planning implications of the visualisations (e.g., Afrooz et al., 2018; Pouke et al., 2019), while some publications highlighted the technical solution's novelty with little conceptual or empirical link to planning practice (e.g., Dembski et al., 2020). Case study publications

A Usability evaluation methods (n=24)

	No.	%
Questionnaire	20	83.3
Interviews	6	25.0
Observations	3	12.5
Video or audio recordings	2	8.3
Eye tracking metrics	1	4.2
Internet analytics	1	4.2
Feedback emails	1	4.2
Completion of usability testing tasks	1	4.2
Interviews of experts not users	1	4.2

B Sampling type (n=32)

	No.	%
Purposive sampling	15	46.9
Volunteered participation	11	34.3
Convenience sampling	5	15.6
Random sampling	2	6.3
Quota sampling	1	3.1

Fig. 7. Usability evaluation methods (A) and sampling types for selecting the test users in the case studies (B).

that comprehensively describe all three aspects, namely the technology, its usability, and implications to planning, were non-existent in the reviewed literature. If the technology or the purposes or tasks for which the technology was used are not well described in a publication, it is difficult to decipher what the usability evaluation actually tested. Similarly, if the usability evaluation itself is insufficiently described the rigour of evidence is obscured.

The technical characteristics of the reviewed 3D visualisations support the observations in other reviews (Billger et al., 2017; Julin et al., 2018) that a wide range of technical solutions are available for developers. In fact, nearly all cases were unique from this viewpoint. It is worth noting that, in over two-thirds of the cases, the 3D visualisation was displayed in a 2D format that is straightforward to share on traditional screens but usually found to provide a less immersive experience to the user (Çöltekin et al., 2016). Immersive solutions, such as HMD or CAVE, were reported in one-third of the cases. These results are in line with the previous research estimating that cross-platform compatible techniques (Evans et al., 2014; Mouton et al., 2011) and techniques that are convenient for public use (Çöltekin et al., 2016; Jaalama et al., 2021) are more likely to be adopted in the participatory processes. While immersive solutions for viewing are becoming less costly and more accessible, what is considered practical for a particular participatory or collaborative planning context will have a central role in the selection of which display technologies are deployed in the future and how the participants will perceive the visualisation experience. In addition, for the adoption of 3D visualisation-based tools and scalability of the technology, open source data and solutions are of importance. The production of 3D models using openly available or low-cost data and software and offering them as open source to stakeholders to utilize enable their adoption when commercial 3D models are unattainable (Girindran et al., 2020; Julin et al., 2018). We were unable in most reviewed cases to identify if the used technical solution was open source. Thus, it is advisable, that open sourcing with the respective technical solution is described as part of the research reporting, and more importantly, encouraged to be made use of.

The most common way to participate in individual exercises was online through the participants' own device, such as a computer, that facilitates wider stakeholder involvement in communicative planning. However, exercises with special hardware that enable a more immersive experience and collaborative setting with smaller groups of stakeholders are also pertinent but less common for example a VR environment that is cross-compatible with CAVE, HMD and other display types (Dembski et al., 2020) and virtual reality laboratory with 3D visualisation projected onto a large curved screen (Hassan et al., 2014). This exemplifies the different focuses in the field for developing or applying tools for different types of stakeholder engagement and phases and purposes in planning processes. Moreover, the 3D visualisation application in most of the case studies took advantage of the visualisation power, rich content and functionalities that digital 3D environments enable; the different levels of realism were visualised, and the users were able in many cases to examine the planning area from various perspectives (in real time 3D), explore different information parameters, and, in quite a few cases, also create their own designs. Nonetheless, almost one fifth of the cases allowed less human–computer interaction, because the 3D visualisation was only presented from a predefined viewing perspective, such as with still images or videos thus inhibiting further exploration of the data and new knowledge construction as envisioned for the use of geovisualisations (Batty, 2018; Ketzler et al., 2020; MacEachren et al., 2004). Interestingly, most communication between planners and participants and among participants happened non-digitally when the 3D visualisations were used, indicating that 3D visualisations are often used to inspire and facilitate face-to-face discussion despite being digital solutions. Thus, the 3D visualisations are usually a medium to convey information on the planning area but not a medium for digital communication between people.

Following the fourfold categorization of communicative actions in planning (Staffans, Kahila-Tani, Geertman, et al., 2020), participation of users was more common among the cases compared to collaboration. These results are in line with earlier studies that have revealed that information and communication technology enabled tools are mostly used for broad public participation and for opening up the planning process for diverse interests and opinions (Staffans, Kahila-Tani, & Kyttä, 2020). In the reviewed literature, the most common purposes for using the 3D visualisation in planning were related to facilitating opinion formation, commenting and discussion among participants. Some cases took even further steps and utilised 3D visualisation to facilitate collaborative design or plan creation. Four of these cases used gamified 3D visualization to engage youth – often silent-voices in planning – and enhance their understanding on socio-spatial phenomena to be addressed via urban or landscape planning. The possibility of providing a multisensory experience of the planning area to participants was used in three case studies that combined soundscape with the visualisation (Echevarria Sanchez et al., 2017; Ruotolo et al., 2013; Yu et al., 2018), a fairly new arena of research on environmental perception and an important part of people's mental image of a place (Dai & Zheng, 2021; Lindquist & Lange, 2014). Based on these main purposes of using the visualisation, it can be said that the visualisations were mainly developed to facilitate either the planning process phases of visioning or exploring and commenting of the proposed plans. Examples of using 3D visualisations in the very early phase of planning, as in goal setting, or in the last phase of communicating the final proposal did not feature in the reviewed literature.

Only a half of the publications offer any, and often limited, indication of the usability of the 3D visualisations. Even though the test users of the 3D visualisation were representatives of the targeted end users in most cases, robust usability evaluation with users was rare. For example, the most common type of usability evaluation in the cases, namely user feedback collection, a form of participant-based evaluation methods, is limited in providing objective evidence. This is because it relies on users' perceptions of the usability and is, hence, indicative and bears less weight as evidence of usability compared to user testing and observation or a combination of several usability evaluation methods (Hall et al., 2017). Generally, the robustness of a usability evaluation is determined by a combined use of several supplementary evaluation methods in a study, carrying out the evaluation in (simulated) real-life setting, thorough reporting of evaluation criteria and the representativeness of the test users, e.g. in terms of their number and representativeness of the actual end users of the application (Benyon, 2019; Nielsen, 1994). In our review, the rare cases where technologies to track users' visual engagement (e.g., view orientation and time) with the 3D platforms were used (Dahlhaus et al., 2016; Klein et al., 2016) offer promising supplementary methods for usability and utility evaluations (Tomkins et al., 2019). It is also noteworthy that expert-based methods were non-existent, although they are affordable and lightweight methods that can be applied in different phases of digital tool development and can supplement the participant-based methods (Benyon, 2019).

In the reviewed case studies, the background information of the test users was often limited to general description or the gender and age distribution of the users. In order to evaluate the usability of 3D visualisations among various user groups, e.g. the elderly, people with lower level of education or those less familiar with the planning area, disclosing information on the test users' background is important and a requirement in robust usability evaluations (Nielsen, 1994). While among the aims of communicative planning are wider public participation and acceptability of decisions including engagement of marginalized social groups in planning processes, case studies that investigate the inclusivity of the technology and the engagement process are needed. However, based on the case studies in our review, little can be said about how the visualisations fare in engaging diverse citizenry, in particular marginalized groups, and supporting different planning tasks and communicative purposes. Hence, this review highlights that the studies in the field should better take into consideration the test users' representativeness, inclusivity of the planning process and the robustness in usability evaluation to build a more convincing evidence base regarding the usability of different 3D visualisations.

4.2. Identified research and development needs

While discussions on the applicability and potential of 3D visualisations in communicative planning practice are prolific among professionals and academics, scientific knowledge is limited. Particularly the impacts of 3D visualisations on participation and collaboration have lacked rigorous scientific evaluation. Due to the differing paradigms and academic routines, scientific reporting varied greatly within the reviewed publications. A fairly large proportion of publications in our review had limited amounts of details about the 3D visualisation technology and its application. Therefore, the results call for a common framework for the 3D visualisation-oriented research agenda and reporting in the multidisciplinary era of technology research. A systematic and transparent reporting of the empirical cases would better serve research accountability, assessment of research findings and the build-up of knowledge base for systematic reviews of evidence (Collaboration for Environmental Evidence, 2013; Petticrew & Roberts, 2006).

We initially expected to have a larger number of publications to review across all the different scientific fields we searched. Our search databases were limited to Scopus and Web of Science (together with a secondary search on Google Scholar), so it is possible that some publications were left out. However, our review focusing on scientific literature sheds light on the prerequisites, aims, outcomes and usability evaluations prevalent in the scientific reporting of user studies and contributes to the academic discussion on the use of 3D visualisations in communicative urban and landscape planning. That said, carrying out a systematic mapping of literature in a field as diverse and dynamic as 3D visualisation and communicative planning shows challenges for generating evidence-based knowledge such as varying study designs, reporting styles and terminology, and no generally agreed mechanisms to assess research validity. Hall et al. (2017) highlighted similar challenges in reviews in built environment planning, such as use of varied and non-standardised sample sizes, experimental methods and the pressure for novel approaches. In this review process, the collaboration and discussions between the co-authors, who included architects and urban planners, geographers, and IT specialists, proved invaluable for filtering and capturing relevant publications from the diverse field and to comprehend the contents and contributions of each publication. This highlights that an inter- and transdisciplinary knowledge sharing helps to integrate and make sense of the technical and participatory aspects of the 3D visualisations intended for communicative planning.

Based on our systematic mapping of literature, we suggest a four-category framework for developing and reporting the use of 3D visualisations in the context of communicative urban and landscape planning in order for researchers, developers and planners to build a more comprehensive evidence base (Fig. 8). The variables were inductively derived while analysing the reviewed literature and ensure that the technological solution and its application contexts are comprehensively reported in a publication. The four categories entail 1) how and based on what information the visualisations are produced and which preconditions they set to visualisation content; 2) how the visualisation is conveyed to the users thus conditioning the human–computer interaction, immersiveness of the 3D experience and human-to-human communication; and 3) for what kind of stakeholder engagement and 4) planning contexts and purposes the 3D visualisation is intended to be

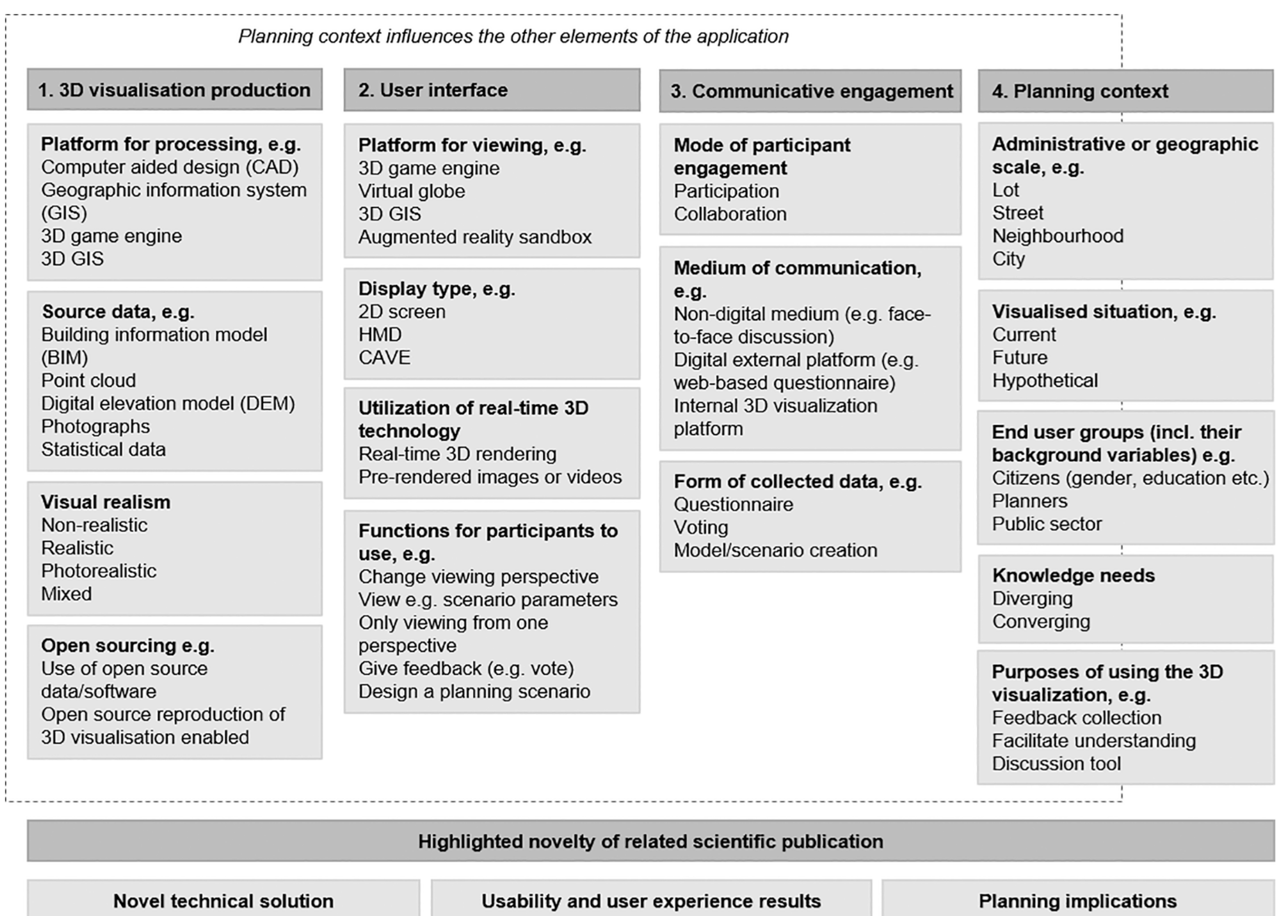


Fig. 8. Framework for developing and reporting 3D visualisations for communicative urban and landscape planning.

used. All of which are to some extent interdependent factors in the visualisation development, application and usability evaluation. In our review process, we deemed the variables in each category necessary to allow evaluation of the quality of the empirical cases and their possible usability evaluations. The framework also emphasises the interrelatedness of the variables that guides the development of 3D visualisation applications to particular planning contexts. For example, a recent study by Chassin et al. (2022) demonstrate that the characteristics of the users as well as the display type and interactivity of the application impact the users' understanding of the visualisation and its usability. Similarly, a review by Nasr-Azadani et al. (2022) concludes that the level of participants' decision-making competency (e.g. systems thinking, geospatial understanding) may influence successful citizen engagement and should thus be considered when designing or selecting visualisations for participatory planning. The literature we reviewed reported these aspects varyingly, mainly depending on the highlighted novelty of the case study. Together with robust usability evaluations, a more adequate description of all aspects (topics) highlighted in this framework in future case study reporting would offer more details of the visualisation and its applicability and, hence, enlighten our understanding of which 3D visualisations suit what communicative planning contexts.

5. Conclusions

Our findings from the academic literature highlight the heterogeneity of planning contexts and purposes and technological solutions of the 3D visualisations applied in communicative urban and landscape planning. The visualisations were mainly developed to facilitate communicative planning in the visioning, plan exploration and evaluation phases of the process. Apart from being applied to facilitate human-to-human communication especially with both diverging and converging knowledge generation in planning processes, the 3D visualisations were also used to inform and raise awareness among the public and other stakeholders of the planning area and different phenomena affecting living environments. The visualisations were mostly a medium for conveying information and inspiring discussion rather than a medium allowing digital 3D communication between people, since most communication between planners and participants and among participants happened non-digitally separate from the 3D space.

Currently the field of 3D visualisation faces wide interest in urban and landscape planning practice by municipalities, private sector developers and civil society actors (see, e.g., Ketzler et al., 2020 for a grey literature review on digital twin usage in cities). Our results highlight a research-practise gap. This gap risks scholarly work to not create applicable knowledge of the usability but also inhibits critical evaluation of the benefits and limitations of 3D visualisations from communicative planning theory perspective in the complex reality of planning. The scientific discussions of 3D visualisations, therefore, exhibit a similar lack of relevance to planning practice that has been noted concerning the broader development of planning support systems (see e.g. Pelzer, 2017). Furthermore, the robustness of the usability evaluations of 3D visualisations called for by Lovett et al. (2015) is still often low among the reviewed research. Our review shows that there is not enough scientific evidence to evaluate how different 3D visualisations fare in delivering envisioned benefits to communicative planning purposes. As an outcome of the systematic mapping we suggest a common framework for developing and reporting 3D visualisations in order for academic literature to better serve systematic analysis of evidence and enhance the commensurability of the empirical case studies.

CRediT authorship contribution statement

Salla Eilola: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Kaisa Jaalama:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Petri Kangassalo:** Conceptualization, Formal analysis, Writing – review & editing. **Pilvi Nummi:** Conceptualization, Formal analysis, Writing – review & editing. **Aija Staffans:** Conceptualization, Formal analysis, Writing – review & editing. **Nora Fagerholm:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The review data is available at http://urn.fi/urn:nbn:fi:att:d6e64a5a-24c6-44f6-80ca-8f4ca5666cf6.

Acknowledgements

This work has been supported by the Academy of Finland (grant no. 321555), the European Commission H2020 (grant no. 856602), the City of Helsinki Innovation fund, and the European Social Fund (grant no. S21997).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2023.104716.

References

Andrienko, G., Andrienko, N., Keim, D., MacEachren, A. M., & Wrobel, S. (2011). Challenging problems of geospatial visual analytics. *Journal of Visual Languages & Computing, 22*(4), 251–256. https://doi.org/10.1016/j.jvlc.2011.04.001

Atwa, S. M. H., Ibrahim, M. G., Saleh, A. M., & Murata, R. (2019). Development of sustainable landscape design guidelines for a green business park using virtual reality. *Sustainable Cities and Society, 48*, Article 101543. https://doi.org/10.1016/j.scs.2019.101543

Afrooz, A., Ballal, H., & Pettit, C. (2018). Implementing augmented reality sandbox in geodesign: A future. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4*(4), 5–12. https://doi.org/10.5194/isprs-annals-IV-4-5-2018

Barros, P., Ng Fat, L., Garcia, L. M. T., Slovic, A. D., Thomopoulos, N., de Sá, T. H., Morais, P., & Mindell, J. S. (2019). Social consequences and mental health outcomes of living in high-rise residential buildings and the influence of planning, urban design and architectural decisions: A systematic review. *Cities, 93*, 263–272. https://doi.org/10.1016/j.cities.2019.05.015

Batty, M. (2018). Digital twins. *Environment and Planning B: Urban Analytics and City Science, 45*(5), 817–820. https://doi.org/10.1177/2399808318796416

Batty, M., & Hudson-smith, A. (2014). *Visual Analytics for Urban Design* (No. 197; UCL Working Papers Series).

Benyon, D. (2019). *Designing user experience. A guide to HCI, UX and interaction design* (4th ed.). Pearson Education Ltd.

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., & Çöltekin, A. (2015). Applications of 3D city models: State of the art review. *ISPRS International Journal of Geo-Information, 4*(4), 2842–2889. https://doi.org/10.3390/ijgi4042842

Billger, M., Thuvander, L., & Wästberg, B. S. (2017). In search of visualization challenges: The development and implementation of visualization tools for supporting dialogue in urban planning processes. *Environment and Planning B: Urban Analytics and City Science, 44*(6), 1012–1035. https://doi.org/10.1177/0265813516657341

Bleisch, S. (2012). 3D Geovisualization - Definition and Structures for the Assessment of Usefulness. In M. Shortis, J. Shi, & E. Guilbert (Eds.), *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 1–2, 129–134. 10.5194/isprsannals-I-2-129-2012.

Bouzguenda, I., Fava, N., & Alalouch, C. (2021). Would 3D digital participatory planning improve social sustainability in smart cities? *An Empirical Evaluation Study in Less-Advantaged Areas*. https://doi.org/10.1080/10630732.2021.1900772. 10(1080/10630732), pp. 1900772, 2021

Celio, E., Ott, M., Sirén, E., & Grêt-Regamey, A. (2015). A prototypical tool for normative landscape scenario development and the analysis of actors' policy preferences. *Landscape and Urban Planning, 137*, 40–53. https://doi.org/10.1016/j.landurbplan.2014.12.013

Chassin, T., Ingensand, J., Christophe, S., & Touya, G. (2022). Experiencing virtual geographic environment in urban 3D participatory e-planning: A user perspective. *Landscape and Urban Planning, 224*, Article 104432. https://doi.org/10.1016/J.LANDURBPLAN.2022.104432

Chaves, R., Schneider, D., Correia, A., Borges, M. R. S., & Motta, C. (2019). Understanding crowd work in online crowdsourcing platforms for urban planning:

Systematic review. *Proceedings of the 2019 IEEE 23rd International Conference on Computer Supported Cooperative Work in Design, CSCWD 2019*, 273–278. 10.1109/CSCWD.2019.8791936.

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*, 37–46.

Collaboration for Environmental Evidence. (2013). *Guidelines for Systematic Review and Evidence Synthesis in Environmental Management*. Version 4.2. Environmental Evidence. www.environmentalevidence.org/Documents/Guidelines/Guidelines4.2.pdf.

Çöltekin, A., Lokka, I., & Zahner, M. (2016). On the usability and usefulness of 3D (Geo) Visualizations – A focus on virtual reality environments. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences – ISPRS Archives, 41* (July), 387–392. https://doi.org/10.5194/isprsarchives-XLI-B2-387-2016

Çöltekin, A., Oprean, D., Wallgrün, J. O., & Klippel, A. (2019). Where are we now? Re-visiting the Digital Earth through human-centered virtual and augmented reality geovisualization environments. *International Journal of Digital Earth, 12*(2), 119–122. https://doi.org/10.1080/17538947.2018.1560986

Dahlhaus, P., Murphy, A., MacLeod, A., Thompson, H., McKenna, K., & Ollerenshaw, A. (2016). Making the invisible visible: The impact of federating groundwater data in Victoria, Australia. *Journal of Hydroinformatics, 18*(2), 238–255. https://doi.org/10.2166/hydro.2015.169

Dai, T., & Zheng, X. (2021). Understanding how multi-sensory spatial experience influences atmosphere, affective city image and behavioural intention. *Environmental Impact Assessment Review, 89*, Article 106595. https://doi.org/10.1016/j.eiar.2021.106595

Dambruch, J., & Krämer, M. (2014). Leveraging public participation in urban planning with 3D web technology. *Proceedings of the 19th International ACM Conference on 3D Web Technologies, Web3D 2014*, 117–124. 10.1145/2628588.2628591.

Dembski, F., Wössner, U., Letzgus, M., Ruddat, M., & Yamu, C. (2020). Urban digital twins for smart cities and citizens: The case study of herrenberg, germany. *Sustainability (Switzerland), 12*(6), 1–17. https://doi.org/10.3390/su12062307

Dix, A., Finlay, J., Abowd, G. D., & Beale, R. (2004). *Human-computer interaction* (3rd ed.). Pearson Education Limited.

Döllner, J. (2007). Non-photorealistic 3D geovisualization. In *Multimedia Cartography* (second ed., pp. 229–240). Berlin Heidelberg: Springer. https://doi.org/10.1007/978-3-540-36651-5_16.

EBDJ. (2015). The knowledge problem: As architects and designers, what do we know about people? *Evidence Based Design Journal.* http://ebdjournal.com/blog/general-design/the-knowledge-problem.

Echevarria Sanchez, G. M., Van Renterghem, T., Sun, K., De Coensel, B., & Botteldooren, D. (2017). Using Virtual Reality for assessing the role of noise in the audio-visual design of an urban public space. *Landscape and Urban Planning, 167* (May), 98–107. https://doi.org/10.1016/j.landurbplan.2017.05.018

Eilola, S., Jaalama, K., Kangassalo, P., Nummi, P., Staffans, A., & Fagerholm, N. (2021). Review of 3D visualisations supporting communication in urban and landscape planning. Systematic review protocol. Unpublished. https://sites.utu.fi/greenplace/wp-content/uploads/sites/558/2022/07/3D-participatory-review_PROTOCOL_30.6.2021_UPDATED-compressed.pdf.

Engman, H. (2016). Examples and critical success factors – Web-based 3D in Urban Planning. *GIM International*, 3–4. https://www.gim-international.com/content/article/web-based-3d-in-urban-planning.

Evans, A., Romeo, M., Bahrehmand, A., Agenjo, J., & Blat, J. (2014). 3D graphics on the web: A survey. *Computers and Graphics (Pergamon), 41*(1), 43–61. https://doi.org/10.1016/j.cag.2014.02.002

Fagerholm, N., Torralba, M., Burgess, P. J., & Plieninger, T. (2016). A systematic map of ecosystem services assessments around European agroforestry. *Ecological Indicators, 62*, 47–65. https://doi.org/10.1016/j.ecolind.2015.11.016

Falco, E., & Kleinhans, R. (2018). Digital participatory platforms for co-production in urban development: A systematic review. *International Journal of E-Planning Research, 7*(3), 1–27. https://doi.org/10.4018/IJEPR.2018070105

Fiorino, D. J. (1990). Citizen participation and environmental risk: A survey of institutional mechanisms. *Science, Technology, & Human Values, 15*(2), 226–243. https://doi.org/10.1177/016224399001500204

Fisher, R., Heckbert, S., Maria, J., & Sutton, S. (2019). Augmenting physical 3D models with projected information to support environmental knowledge exchange. *Applied Geography, 112*(October), 1–10. https://doi.org/10.1016/j.apgeog.2019.102095

Forester, J. (1999). *The deliberative practitioner: Encouraging participatory planning processes*. MIT Press.

Garcia-Martin, M., Fagerholm, N., Bieling, C., Gounaridis, D., Kizos, T., Printsmann, A., Müller, M., Lieskovský, J., & Plieninger, T. (2017). Participatory mapping of landscape values in a Pan-European perspective. *Landscape Ecology, 32*(11), 2133–2150. https://doi.org/10.1007/s10980-017-0531-x

Gill, L., & Lange, E. (2015). Getting virtual 3D landscapes out of the lab. *Computers, Environment and Urban Systems, 54*, 356–362. https://doi.org/10.1016/j.compenvurbsys.2015.09.012

Gill, L., Lange, E., Morgan, E., & Romano, D. (2013). An analysis of usage of different types of visualisation media within a collaborative planning workshop environment. *Environment and Planning B: Planning and Design, 40*(4), 742–754. https://doi.org/10.1068/b38049

Girindran, R., Boyd, D. S., Rosser, J., Vijayan, D., Long, G., & Robinson, D. (2020). On the Reliable Generation of 3D City Models from Open Data. *Urban Science, 4*, 47. https://doi.org/10.3390/urbansci4040047

Gordon, E., Schirra, S., & Hollander, J. (2011). Immersive planning: A conceptual model for designing public participation with new technologies. *Environment and Planning B: Planning and Design, 38*(3), 505–519. https://doi.org/10.1068/b37013

Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. *Research Synthesis Methods, 11*(2), 181–217. https://doi.org/10.1002/jrsm.1378

Hall, S., Oldfield, P., Mullins, B. J., Pollard, B., & Criado-Perez, C. (2017). Evidence based practice for the built environment: Can Systematic reviews close the research – Practice gap? *Procedia Engineering, 180*, 912–924. https://doi.org/10.1016/j.proeng.2017.04.341

Hassan, R., Hansen, T. B., & Nordh, H. (2014). Visualizations in the planning process. *Rethinking Comprehensive Design: Speculative Counterculture - Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2014*, 65–74.

Healey, P. (2006). *Collaborative Planning - Shaping Places in Fragmented Societies* (2nd editio). Palgrave Macmillan. https://www.macmillanihe.com/page/detail/Collaborative-Planning/?K=9781403949202.

Herbert, G., & Chen, X. (2015). A comparison of usefulness of 2D and 3D representations of urban planning. *Cartography and Geographic Information Science, 42*(1), 22–32. https://doi.org/10.1080/15230406.2014.987694

Ho, S., Rajabifard, A., & Kalantari, M. (2015). "Invisible" constraints on 3D innovation in land administration: A case study on the city of Melbourne. *Land Use Policy, 42*, 412–425. https://doi.org/10.1016/j.landusepol.2014.08.017

Hruby, F., Ressl, R., & de la Borbolla del Valle, G. (2019). Geovisualization with immersive virtual environments in theory and practice. *International Journal of Digital Earth*, *12*(2), 123–136. 10.1080/17538947.2018.1501106.

IAP2. (2014). *IAP2 Core values*. www.iap2.org/page/corevalues.

Innes, J. E., & Booher, D. E. (2007). Reframing public participation: strategies for the 21st century. *Http://Dx.Doi.Org/10.1080/1464935042000293170*, *5*(4), 419–436. 10.1080/1464935042000293170.

Jaalama, K., Fagerholm, N., Julin, A., Virtanen, J.-P., Maksimainen, M., & Hyyppä, H. (2021). Sense of presence and sense of place in perceiving a 3D geovisualization for communication in urban planning – Differences introduced by prior familiarity with the place. *Landscape and Urban Planning, 207*, Article 103996. https://doi.org/10.1016/j.landurbplan.2020.103996

Julin, A., Jaalama, K., Virtanen, J.-P., Maksimainen, M., Kurkela, M., Hyyppä, J., & Hyyppä, H. (2019). Automated multi-sensor 3D reconstruction for the web. *ISPRS International Journal of Geo-Information, 8*(5), 221. https://doi.org/10.3390/ijgi8050221

Julin, A., Jaalama, K., Virtanen, J. P., Pouke, M., Ylipulli, J., Vaaja, M., Hyyppä, J., & Hyyppä, H. (2018). Characterizing 3d city modeling projects: Towards a harmonized interoperable system. *ISPRS International Journal of Geo-Information, 7*(2). https://doi.org/10.3390/ijgi7020055

Kahila-Tani, M. (2015). *Reshaping the planning process using local experiences: Utilising PPGIS in participatory urban planning* [Aalto University]. http://urn.fi/URN:ISBN:000-000-00-00.

Kedron, P., Frazier, A. E., Trgovac, A. B., Nelson, T., & Fotheringham, A. S. (2021). Reproducibility and replicability in geographical analysis. *Geographical Analysis, 53* (1), 135–147. https://doi.org/10.1111/GEAN.12221

Kent, L., Snider, C., & Hicks, B. (2019). Engaging Citizens with Urban Planning Using City Blocks, a Mixed Reality Design and Visualisation Platform. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *11614 LNCS*(March 2020), 51–62. 10.1007/978-3-030-25999-0_5.

Ketzler, B., Naserentin, V., Latino, F., Zangelidis, C., Thuvander, L., & Logg, A. (2020). Digital twins for cities: A state of the art review. *Built Environment, 46*(4), 547–573. https://doi.org/10.2148/benv.46.4.547

Kitchenham, B. A., Budgen, D., & Brereton, O. P. (2010). *The value of mapping studies – A participant-observer case study*. 10.14236/EWIC/EASE2010.4.

Klein, T. M., Drobnik, T., & Grêt-Regamey, A. (2016). Shedding light on the usability of ecosystem services-based decision support systems: An eye-tracking study linked to the cognitive probing approach. *Ecosystem Services, 19*(2016), 65–86. https://doi.org/10.1016/j.ecoser.2016.04.002

Konisranukul, W., & Tuaycharoen, N. (2013). Using 3D visualisation to improve public participation in sustainable planning process: Experiences through the creation of Koh Mudsum Plan, Thailand. *Procedia – Social and Behavioral Sciences, 91*, 679–690. https://doi.org/10.1016/j.sbspro.2013.08.469

Kwon, S., Sylte, S., Awadhiya, A., Lindquist, M., Gell, G., & Admassu, K. A. (2019). Land. info: Interactive 3D visualization for public space design ideation in neighborhood planning. *Conference on Human Factors in Computing Systems - Proceedings*, *April*, 0–6. 10.1145/3290607.3312967.

Labib, S. M., Lindley, S., & Huck, J. J. (2020). Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. *Environmental Research, 180*(May 2019), 108869. 10.1016/j.envres.2019.108869.

Laufs, J., Borrion, H., & Bradford, B. (2020). Security and the smart city: A systematic review. *Sustainable Cities and Society, 55*, Article 102023. https://doi.org/10.1016/j.scs.2020.102023

Li, J., & Fan, X. (2014). Outdoor augmented reality tracking using 3D city models and game engine. *Proceedings - 2014 7th International Congress on Image and Signal Processing, CISP 2014*, 104–108. 10.1109/CISP.2014.7003758.

Lieske, S. N., Martin, K., Grant, B., & Baldwin, C. (2015). Visualization Methods for Linking Scientific and Local Knowledge of Climate Change Impacts. In S. Geertman, J. Ferreira, R. Goodspeed, & J. Stillwell (Eds.), *Planning Support Systems and Smart Cities, Lecture Notes in Geoinformation and Cartography* (pp. 373–389). 10.1007/978-3-319-18368-8.

Lindquist, M., & Lange, E. (2014). *Sensory Aspects of Simulation and Representation in Landscape and Environmental Planning: A Soundscape Perspective* (pp. 93–106). 10.1007/978-3-319-03798-1_9.

Lovett, A., Appleton, K., Warren-Kretzschmar, B., & Von Haaren, C. (2015). Using 3D visualization methods in landscape planning: An evaluation of options and practical issues. *Landscape and Urban Planning, 142*, 85–94. https://doi.org/10.1016/j.landurbplan.2015.02.021

MacEachren, A. M. (2001). An evolving cognitive-semiotic approach to geographic visualization and knowledge construction. *Information Design Journal, 10*(1), 26–36. https://doi.org/10.1075/idj.10.1.06mac

MacEachren, A. M., Gahegan, M., Pike, W., Brewer, I., Cai, G., Lengerich, E., & Hardistry, F. (2004). Geovisualization for knowledge construction and decision-support. *Computer Graphics & Applications, 24*(1), 13–17. https://doi.org/10.1109/mcg.2004.1255801

Magnussen, R., & Elming, A. L. (2017). Student re-design of deprived neighbourhoods in minecraft: Methods in Cities at Play Study design, methods and data analysis. *Community-Driven Urban Development.*, 271–278.

Mell, I. C., Henneberry, J., Hehl-Lange, S., & Keskin, B. (2016). To green or not to green: Establishing the economic value of green infrastructure investments in The Wicker, Sheffield. *Urban Forestry and Urban Greening, 18*, 257–267. https://doi.org/10.1016/j.ufug.2016.06.015

Menconi, M. E., & Grohmann, D. (2018). Participatory retrofitting of school playgrounds: Collaboration between children and university students to develop a vision. *Thinking Skills and Creativity, 29*(March), 71–86. https://doi.org/10.1016/j.tsc.2018.06.006

McCormick, B. H., De Fanti, T. A., & Brown, M. D. (1987). Visualization in scientific computing. *Computer Graphics, 21*(6), 1–21.

Moghadam, S. N. M., & Rafieian, M. (2019). What did urban studies do for women? A systematic review of 40 years of research. *Habitat International, 92*, Article 102047. https://doi.org/10.1016/j.habitatint.2019.102047

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., … Whitlock, E. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews, 4*(1). https://doi.org/10.1186/2046-4053-4-1

Morrison, T., & Rubin, M. (2015). Understanding and Living the Past and the Future: 3D Modelling and Interactive Surveys as a Research and Teaching Methodology. *Proceedings of The 14th European Conference on Research Methodology for Business and Management Studies*.

Mouton, C., Sons, K., & Grimstead, I. (2011). Collaborative visualization: Current systems and future trends. *Proceedings - 16th International Conference on 3D Web Technology, Web3D 2011*, 101–109. 10.1145/2010425.2010444.

Nasr-Azadani, E., Wardrop, D., & Brooks, R. (2022). Is the rapid development of visualization techniques enhancing the quality of public participation in natural resource policy and management? A systematic review. *Landscape and Urban Planning, 228*, Article 104586. https://doi.org/10.1016/j.landurbplan.2022.104586

Newell, R., Canessa, R., & Sharma, T. (2017). Visualizing our options for coastal places: Exploring realistic immersive geovisualizations as tools for inclusive approaches to coastal planning and management. *Frontiers in Marine Science, 4*(SEP), 1–19. https://doi.org/10.3389/fmars.2017.00290

Nielsen, J. (1994). *Usability Engineering* (1st ed.). Morgan Kaufmann.

Nishita, C., & Terada, T. (2019). Building Virtual age-friendly communities in minecraft: Media review. *Journal of Intergenerational Relationships, 17*(1), 118–122. https://doi.org/10.1080/15350770.2019.1551666

Onyimbi, J. R., Koeva, M., & Flacke, J. (2018). Public participation using 3D web-based city models: Opportunities for e-participation in Kisumu, Kenya. *ISPRS International Journal of Geo-Information, 7*(12). https://doi.org/10.3390/ijgi7120454

Orland, B., Budthimedhee, K., & Uusitalo, J. (2001). Considering virtual worlds as representations of landscape realities and as tools for landscape planning. *Landscape and Urban Planning, 54*(1–4), 139–148. https://doi.org/10.1016/S0169-2046(01)00132-3

Patterson, Z., Darbani, J. M., Rezaei, A., Zacharias, J., & Yazdizadeh, A. (2017). Comparing text-only and virtual reality discrete choice experiments of neighbourhood choice. *Landscape and Urban Planning, 157*, 63–74. https://doi.org/10.1016/j.landurbplan.2016.05.024

Pelzer, P. (2017). Usefulness of planning support systems: A conceptual framework and an empirical illustration. *Transportation Research Part A: Policy and Practice, 104*, 84–95. https://doi.org/10.1016/j.tra.2016.06.019

Petticrew, M., & Roberts, H. (2006). *Systematic reviews in the social sciences: a practical guide*. Blackwell Publishing Inc. 10.5860/choice.43-5664.

Polys, N., Newcomb, C., Schenk, T., Skuzinski, T., & Dunay, D. (2018). The value of 3D models and immersive technology in planning urban density. *Proceedings - Web3D 2018: 23rd International ACM Conference on 3D Web Technology*, *December*. doi: 10.1145/3208806.3208824.

Portman, M. E., Natapov, A., & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. *Computers, Environment and Urban Systems, 54*, 376–384. https://doi.org/10.1016/j.compenvurbsys.2015.05.001

Potts, R. (2020). Is a New 'Planning 3.0' Paradigm Emerging? Exploring the Relationship between Digital Technologies and Planning Theory and Practice. *Planning Theory & Practice, 21*(2), 272–289. https://doi.org/10.1080/14649357.2020.1748699

Pouke, M., Ylipulli, J., Rantala, S., Alavesa, P., Alatalo, T., & Ojala, T. (2019). A Qualitative Study on the Effects of Real-World Stimuli and Place Familiarity on Presence. *2019 IEEE 5th Workshop on Everyday Virtual Reality, WEVR 2019*. 10.1109/WEVR.2019.8809590.

Pullin, A. S., & Knight, T. M. (2009). Doing more good than harm – Building an evidence-base for conservation and environmental management. *Biological Conservation, 142*(5), 931–934. https://doi.org/10.1016/j.biocon.2009.01.010

Pullin, A. S., & Stewart, G. B. (2006). Guidelines for systematic review in conservation and environmental management. *Conservation Biology, 20*(6), 1647–1656. https://doi.org/10.1111/j.1523-1739.2006.00485.x

Rexhepi, A., Filiposka, S., & Trajkovik, V. (2018). Youth e-participation as a pillar of sustainable societies. *Journal of Cleaner Production, 174*, 114–122. https://doi.org/10.1016/j.jclepro.2017.10.327

Ruotolo, F., Maffei, L., Di Gabriele, M., Iachini, T., Masullo, M., Ruggiero, G., & Senese, V. P. (2013). Immersive virtual reality and environmental noise assessment: An innovative audio-visual approach. *Environmental Impact Assessment Review, 41*, 10–20. https://doi.org/10.1016/j.eiar.2013.01.007

Scholten, H., Fruijtier, S., Dias, E., Hettinga, S., Opmeer, M., van Leeuwen, W. S., Linde, M., Bos, S., Vaughan, R., van Kaam, H., van Manen, N., & Fruijtier, C. (2017). Geocraft as a means to support the development of smart cities, getting the people of the place involved - youth included -. *Quality Innovation Prosperity, 21*(1), 119–150. https://doi.org/10.12776/QIP.V21I1.784

Schroth, O., Pond, E., & Sheppard, S. R. J. (2015). Evaluating presentation formats of local climate change in community planning with regard to process and outcomes. *Landscape and Urban Planning, 142*, 147–158. https://doi.org/10.1016/j.landurbplan.2015.03.011

Serginson, M., Ladinski, V., Giddings, B., & Messer, S. (2013). Assessing the effectiveness of architectural design communication through public participation methods. *International Journal of Design Management and Professional Practice, 6*(1), 61–83. https://doi.org/10.18848/2325-162x/cgp/v06i01/38630

Sharifi, M. A., van den Toorn, W., Rico, A., & Emmanuel, M. (2002). Application of GIS and multicriteria evaluation in locating sustainable boundary between the Tunari National Park and Cochabamba City (Bolivia). *Journal of Multi-Criteria Decision Analysis, 11*(3), 151–164. https://doi.org/10.1002/mcda.323

Staffans, A., Kahila-Tani, M., Geertman, S., Sillanpää, P., & Horelli, L. (2020). Communication-Oriented and Process-Sensitive Planning Support. *International Journal of E-Planning Research, 9*(2), 1–20. https://doi.org/10.4018/ijepr.2020040101

Staffans, A., Kahila-Tani, M., & Kyttä, M. (2020). Participatory urban planning in the digital era. In S. Geertman & J. Stillwell (Eds.), *Handbook of Planning Support Science* (pp. 307–322). Edward Elgar Publishing. 10.4337/9781788971089.00030.

Stone, G. A., Fernandez, M., & DeSantiago, A. (2019). Rural Latino health and the built environment: A systematic review. *Ethnicity and Health*. https://doi.org/10.1080/13557858.2019.1606899

Tabrizian, P., Harmon, B., Petrasova, A., Petras, V., Mitasova, H., & Meentemeyer, R. (2017). Tangible immersion for ecological design. *Disciplines and Disruption - Proceedings Catalog of the 37th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2017*, *November*, 600–609.

Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital Twin in Industry: State-of-the-Art. *IEEE Transactions on Industrial Informatics, 15*(4), 2405–2415. https://doi.org/10.1109/TII.2018.2873186

Tobias, S., Buser, T., & Buchecker, M. (2016). Does real-time visualization support local stakeholders in developing landscape visions? *Environment and Planning B: Planning and Design, 43*(1), 184–197. https://doi.org/10.1177/0265813515603866

Tomkins, A., Hehl-Lange, S., & Lange, E. (2019). Tracking visual engagement in mixed reality: A framework for analysing interaction with digital models. *Journal of Digital. Landscape Architecture, 2019*(4), 160–167. https://doi.org/10.14627/537663017

Van Leeuwen, J. P., Hermans, K., Jylhä, A., Quanjer, A. J., & Nijman, H. (2018). Effectiveness of virtual reality in participatory urban planning. *ACM International Conference Proceeding Series, 128–136*. https://doi.org/10.1145/3284389.3284491

Virtanen, J. P., Hyyppä, H., Kämäräinen, A., Hollström, T., Vastaranta, M., & Hyyppä, J. (2015). Intelligent open data 3D maps in a collaborative virtual world. *ISPRS International Journal of Geo-Information, 4*(2), 837–857. https://doi.org/10.3390/ijgi4020837

Voinov, A., Çöltekin, A., Chen, M., & Beydoun, G. (2018). Virtual geographic environments in socio-environmental modeling: A fancy distraction or a key to communication? *International Journal of Digital Earth, 11*(4), 408–419. https://doi.org/10.1080/17538947.2017.1365961

Wang, C., Miller, D., Brown, I., Jiang, Y., & Castellazzi, M. (2016). Visualisation techniques to support public interpretation of future climate change and land-use choices: A case study from N-E Scotland. *International Journal of Digital Earth, 9*(6), 586–605. https://doi.org/10.1080/17538947.2015.1111949

Wissen Hayek, U. (2011). Which is the appropriate 3D visualization type for participatory landscape planning workshops? A portfolio of their effectiveness. *Environment and Planning B: Planning and Design, 38*(5), 921–939. https://doi.org/10.1068/b36113

Wissen Hayek, U., Spielhofer, R., & Grêt-Regamey, A. (2019). Preparing 3D point clouds as stimuli for landscape preference studies: Lessons learned. *Journal of Digital Landscape Architecture, 2019*(4), 250–257. https://doi.org/10.14627/537663027

Yin, R. K. (2011). *Qualitative research from start to finish*. The Guilford Press.

Yu, T., Behm, H., Bill, R., & Kang, J. (2018). Validity of VR technology on the smartphone for the study of wind park soundscapes. *ISPRS International Journal of Geo-Information, 7*(4), 1–13. https://doi.org/10.3390/ijgi7040152

Zhang, L., Geertman, S., Hooimeijer, P., & Lin, Y. (2019). The usefulness of a Web-based Participatory Planning Support System in Wuhan, China. *Computers, Environment and Urban Systems, 74*, 208–217. https://doi.org/10.1016/J.COMPENVURBSYS.2018.11.006