Using augmented reality in urban planning processes

Sustainable urban transitions through innovative participation

The use of augmented reality applications in urban planning improves the quality of participation processes and contributes to sustainable city development. However, as our case studies also show, these potentials are not fully exploited yet as augmented reality is not yet used in all planning phases.

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Abstract
Sustainable urban development requires innovative approaches and concepts that involve people not only in planning processes but also in influencing the design of urban space. Modern formats, such as augmented reality (AR), can help to increase the motivation for participation and present different planning concepts more realistically through different forms of visualization. Based on case studies in Vienna, Austria, and Lucerne, Switzerland, we examine AR applications in planning participation and discuss the innovative nature of these applications. We show that the use of AR not only increases the motivation of the population to participate in planning processes but also increases the quality of participation processes and can, thus, trigger a sustainable transformation of cities.

Keywords
augmented reality, digital participation, impact on urban planning, sustainable urban transitions, urban planning, virtual reality

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Urban planning can be understood as the process of making decisions to shape and guide the future of our cities – for example, in terms of settlement structures, infrastructures, buildings, and open spaces. For this purpose, planners develop planning concepts and strategies and then present and discuss initial ideas and proposals with interested stakeholders and politicians. In doing so, planners are required to take into account the broader social, ecological, technical, and economic trends and developments as well as locally specific conditions for housing, work, culture, and leisure. Thus, such concepts and plans may include ideas to improve the health conditions or the quality of life in specific neighborhoods by, for example, redesigning streets to foster cycling, building more affordable housing, or increasing the number of parks for families in working class neighborhoods.

Numerous actors with different interests are involved in these urban development processes, with or without prior knowledge of legal regulations, planning instruments, ecological conditions, the cubature of buildings, or similar aspects. Hence, the (visual) information provided to participants needs to be easy to understand (Kikuchi 2022). In this context, spatial imaginations of urban streets, buildings, and neighborhoods have played a major role in public participation in urban development (Höhl and Broschart 2015). Visualization is considered the key for successful participation, as it provides all participants with a shared basis or language (Al-Kodmany 1999, 2002). Consequently, appropriate visual representations are crucial for the building of public opinion and decision-making (Boos et al. forthcoming).

Traditional and analog ways of visualizing and communicating new planning concepts and projects include the preparation of maps, blueprints, and paper-based drawings, often accompanied by photographs and/or physical models to optimize illustrations of the planned project. The succeeding generation of planning or visualizing instruments then incorporated geographical information services (GIS) and computer-aided design (CAD) to map land use, visualize the dimensions of design in a digital environment, and offer perspective three-dimensional (3D) sketches. Finally, 3D city models, based on 3D geospatial data, reproduce the physical city in a virtual world (Al-Kodmany 2002, Billger et al. 2017, Kikuchi et al. 2022, Rohil and Ashok 2022, Wilson and Tewdwr-Jones 2022). As ongoing developments in numerous European cities indicate, "[l]ocal governments [increasingly] use 3D city models for urban planning and environmental simulations such as estimating the shadows cast by buildings [or] investigating how the noise from traffic propagates through a neighborhood" (Biljecki 2017, p. 3). Consequently, visualization tools such as AR have become an essential platform for co-designing with residents in urban spaces (Ruohomäki et al. 2018), highlighting 3D visualizations of intended urban development plans or projects contextually in physical spaces, and simultaneously, co-designing urban interventions in-situ (Lock et al. 2019).

However, existing studies and reports on AR tools and applications often refer to technical prerequisites, application possibilities, etc. (e.g., Beneš et al. 2022, Boos et al. forthcoming, Höhl and Broschart 2015), include cross-analyses of existing publications on AR (e.g., Rohil and Ashok 2022, Wolf et al. 2020), or present AR applications with reference to specific topics (e.g., culture, tourism, transport planning) (Fegert et al. 2021, Kikuchi et al. 2022). Thus far, only a few studies have focused on the use of AR in urban planning processes (e.g., Saßmannshausen et al. 2021, Schürmann et al. 2021). This is the starting point for this article, which considers the following research questions: How is AR used in planning practice? For what purposes and in which planning phases is it used? To what extent can AR contribute to the sustainable transformation of cities, particularly with regard to a more balanced participation of actors and to more transparent participation?

Augmented reality as both a digital visualization and digital participation tool

We see AR as both a digital visualization tool and a digital participation tool. AR was first mentioned and defined by Caudell and Mizell (1992, p. 660) as a technology which "is used to 'augment' the visual field of the user with information necessary in the performance of the current task". This distinguishes AR from VR, which can be described as "a computer-generated artificial environment that makes the users of the device feel as if they are in a different artificial world" (Rohil and Ashok 2022, p. 1, see also Schürmann et al. 2021). In contrast, in AR the representation of digital objects overlaps with reality, thereby implying that actual situations are enriched with additional digital information (Kikuchi et al. 2022, Zeile 2017). In this manner, for example, a digital sketch of planned buildings, streets, or public spaces is projected into the actual environment in real time (Zeile 2017, p. 619, Rohil and Ashok 2022, p. 1).

According to Tomkins and Lange (2020, p. 372), AR offers a novel tool for visualizing a wide variety of data. Thus, AR enables planners, policymakers and other stakeholders such as citizens to experience and better understand the intended changes in the built environment and to identify potential conflicts before a development is implemented in practice. However, a review of existing studies (Schürmann et al. 2021, Fegert et al. 2021, Beneš et al. 2022, Wolf et al. 2020) reveals that AR applications have often been used with regard to specific projects (e.g., a building to be constructed, a street or park to be redesigned, etc.). In these cases, it appears that AR is used when realizing a planned project (but the project itself is no longer under discussion) for presenting variations in the design of the project (e.g., positioning of furniture in a public space, etc.) to raise awareness and acceptance of the intended project. Here, AR – with its different levels of detail (e.g., with regard to building cubature, façade design, shading, etc.) – enables a rather realistic depiction of the intended structural-spatial development (Boos et al. forthcoming). However, whether or not AR applications are also suitable for the discussion on possible planning alternatives (e.g., for the intended residential use of an inner-city brownfield site) at the beginning of strategic planning processes (where the outcome of planning is still largely open) remains debatable.

Providing AR visualization in planning processes can increase motivation and willingness to become involved in participatory events, as AR systems provide new sources of information to support decision-making in the process (Boos et al. forthcoming, p. 5). According to Tomkins and Lange (2020, p. 372), AR "open[s] up new modes of communication and visualization to enhance the widespread practice of model making and could be a flexible tool for designers, students, and stakeholders to analyze and communicate evolving or competing designs in a dynamic context". Therefore, AR visualizations offer manifold, often playful and captivating, interactions with relevant stakeholders (Sankowska 2020). This is in line with the results of other studies (Saßmannshausen et al. 2021, p. 252, Awang et al. 2020, pp. 53 ff.) that highlight how AR can enhance motivational effects on stakeholders, particularly on underrepresented groups such as young people, thereby encouraging participation in planning processes via gamification and other playful approaches.

Further, Awang et al. (2020, pp. 53 ff.) demonstrated that AR applications as a basis for (digital) participation can increase the willingness of stakeholders to participate in public planning processes. They indicated that people prefer the use of 3D objects and the 3D-visualisation of surroundings and building cubature rather than 2D plans (Awang et al. 2020, pp. 54 f.). The selected level of detail of the displayed objects in an AR application also appears to make an impact on the users and, thus, influence the participation process. For example, an AR visualization with a low level of detail could provide a less clear picture of a design, thereby making it easier to engage the public in an early participation process (Boos et al. forthcoming, p. 25). Furthermore, more detailed visualizations can be used to provide a more concrete picture of a project in subsequent planning phases and "could be used for purposes where authorities wish to make a definitive commitment" (Boos et al. forthcoming, p. 25). However, there are very few studies that empirically analyze the extent to which AR can contribute to more effective and efficient

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ways of public participation in planning processes – this relates primarily to the role of initiating and participating actors, the embedding of AR applications in planning processes, and the presentation of planning content in AR presentations. Therefore, the extent to which AR can "assist decision-makers, planners and communities to collectively plan and engage in creating sustainable, liveable and productive cities" remains unclear (Lock et al. 2019, p. 1).

Research design and methodology

To be able to capture current AR applications in urban development processes, we conducted an Internet-based desktop research and literature analysis as well as a case study analysis of two AR-based planning processes in practice. The literature review concentrated on published articles in the *Web of Science, ScienceDirect,* and *Scopus* databases. By using specific search terms such as "3D visualisation", "augmented reality", "virtual reality", "digital participatory planning", "virtual urban planning", "virtual urban reality", and "digital twin", we were, as a first step, able to identify relevant articles. In a second step, we read the abstracts of the identified articles to allow a profound selection of papers that, on the one hand, explain how AR applications work and, on the other hand, have already made initial impact assessments on the use of AR. Thereafter, we selected articles in which the terms and concepts in the abstract strongly overlap with the subject of our study (e. g., articles presenting case studies where AR has been used for a sectoral planning process, etc.). Finally, we selected 30 articles and analyzed them with the aim of deriving criteria for the analysis of the case studies in order to be able to assess the potentials and weaknesses of AR in urban development processes.

According to the literature analysis (see above), we derived three research dimensions that are highly significant for the use of AR applications in practice but have not been researched adequately thus far. This includes stakeholder constellations, transparency, and the presentation of planning content. *Stakeholder constellations* analyze the role of the actors who develop and use AR applications (e. g., urban planning departments, start-ups, research organizations) as well as interactions with potential users (other municipal departments, inhabitants, etc.). This must also be considered in relation to *transparency*. Here, the following aspects are highly relevant to understand the use and impact of AR applications in the planning process: 1. the embeddedness of the AR application in the entire planning process (as well as the integration with analog participation formats); 2. the planning phase or the point in time at which the AR application is used in the planning process (rather open participation in an early planning phase or rather limited participation in a subsequent participation phase); and 3. simple access to and use of the application. The *presentation of planning content* includes the depth of representation and the (visual) innovations that AR applications can bring to consultations in the planning process. What is also of relevance here is which contents are visualized in the application (and in what manner) and which are not, particularly with regard to sustainable development.

We then applied these dimensions in our case study analysis. The identification of relevant case studies for the in-depth analysis of AR applications followed a rather pragmatic research approach, thereby implying that we searched for cases where we could test AR applications in practice and where we could interview the main actors regarding their experiences with the AR applications. This included, among others, planners, app developers, and researchers. On this basis, we selected case studies in Austria (Vienna), Germany (Hamburg, Karlsruhe), and Switzerland (Lucerne), where AR applications have recently been applied or are currently being tested in urban development processes. The case study analysis includes guideline-based expert interviews with involved municipal representatives, representatives of AR companies, and researchers involved in developing and implementing AR in the selected cities. Overall, we conducted nine interviews to identify the opportunities and challenges of AR applications in urban planning processes. Five interviews were linked to the two case studies in Vienna and Lucerne, which are examined in greater detail in the following paragraphs. We selected these two cases because the two AR tools developed here relate to different application areas and dimensions and have only recently been tested in practice. The interviews are evaluated using qualitative content analysis in accordance with Mayring (2015). In this context, the results of the interviews in Vienna and Lucerne were also compared with the results of the interviews from the other cities.

In both cases, the initiators of the AR applications also conducted their own empirical surveys, the results of which were available to us. These results, particularly those pertaining to user groups and user satisfaction, provided further empirical findings that we used to assess the impact of AR in the two case studies. In addition, the case study analysis consists of our own experiences with the respective AR applications (particularly regarding issues such as functionality, degree of presentation – what is presented and what is not –, susceptibility to interference, and comprehensibility), which we were able to gain in the course of self-tests of the AR tools on site. Further, we recorded and evaluated our self-tests in accordance with the methodological procedure for on-site visits. Based on the combination of the results from the expert interviews, the supplementary local surveys and documents, and the self-tests, we then evaluate the case studies before we finally discuss and evaluate the overall potentials and weaknesses of AR applications in planning processes.

Making climate effects visible via augmented reality – Bernardgasse in Vienna

The first case study is an AR application for the redesign of Bernardgasse in Vienna, Austria. The water pipes in Bernardgasse require renewal and, thus, the district authority is taking the opportunity to redesign the entire street with an eye to the future. Currently, the one-way street is characterized by historical residential block perimeter development (figure 1).

The street is a single lane one, the sidewalks are narrow, and parked cars make it crowded, so there is little space left for public use. Bernardgasse is barely landscaped, thereby making it rather warm in the summer (GLARA Forschungskonsortium et al. 2021, pp. 5 f.). The city has already developed initial concepts to make the street more climate-friendly and sustainable through green structures. To illustrate the impact of greening on temperatures, an initial participation process with various analog events and an AR application was initiated in a comparatively early planning phase between October 14 and November 7, 2021. The target group for participation was the immediate neighborhood with residents of Bernardgasse and adjacent side streets. The AR application was developed and tested as part of the *GLARA* research project[1], a consortium comprising different partners such as the seventh Vienna municipal district, architecture and landscape architecture companies (superwien urbanism ZT GmbH and Green4Cities GmbH), a company specializing in the development of digital visualization tools (Fluxguide Ausstellungssysteme GmbH), and an international competence center for urban green infrastructures (tatwort Nachhaltige Projekte GmbH) *(stakeholder constellation)*.

The participation was organized by the *GLARA* project consortium and implemented by using different (analog and digital) methods, which included a "kick-off event", "information points", the "*GLARA* app", and a "survey" (GLARA Forschungskonsortium et al. 2021, pp. 10–13). The *transparent participation process* began with an on-site kick-off event on October 14, 2021. The event was attended by approximately 80 residents, who were involved through "emotional mapping" to communicate their wishes and ideas on the topics of 1. microclimate, 2. quality of stay, 3. traffic and street space (GLARA Forschungskonsortium et al. 2021, p. 10). In addition, their wishes and requirements for the redesigning of the street were considered in small groups. Subsequently, information points were set up along Bernard- >

1 The *GLARA* research project *(Green Living Augmented + Virtual Reality)* aims to create a low-threshold participatory planning process that enables and supports the design of green spaces with the participation of all stakeholders. Therefore, *GLARA* develops various analogue and digital participation formats in order to activate different stakeholders. These formats and tools are currently being used and tested in two case studies in Vienna for the redesign of public spaces (Green4Cities GmbH 2022).

FIGURE 1: Visualization of heat stress, that is, temperatures in Bernardgasse, Vienna, AT, in order to sensitize residents to climate-adapted urban development. Source: *www.fluxguide.com/puls/glara-kick-off-in-der-bernardgasse*.

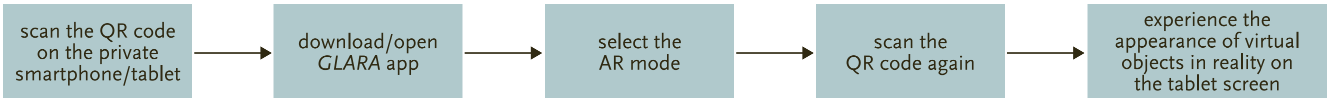


FIGURE 2: Access to and use of an augmented reality (AR) application in Vienna, AT (schematic diagram).

gasse between October 18 and October 22, 2021 (GLARA Forschungskonsortium et al. 2021, p. 12). A total of 90 participants took advantage of this opportunity and contributed additional ideas to the process.

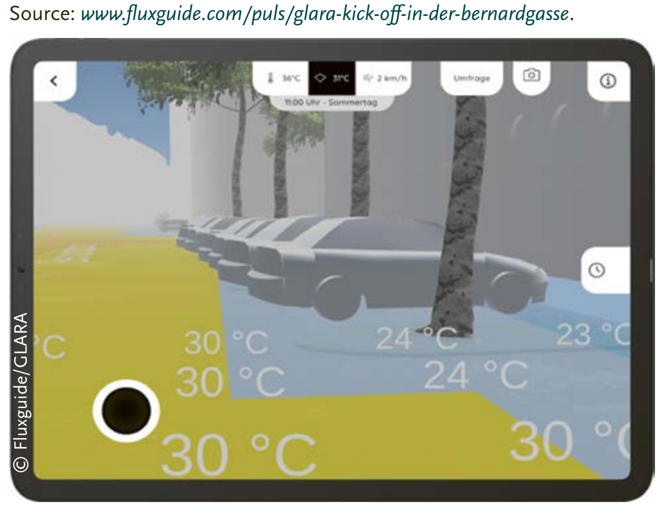
At the same time as the kick-off event, the *GLARA* app was released – an AR application that enabled the public to digitally experience the climatic impacts and effects of urban planning measures for sustainable urban development on hot summer days as well as the actual state of the microclimate in Bernardgasse during the participation phase (GLARA Forschungskonsortium et al. 2021, p. 13). The app was linked to the survey on the redesign of Bernardgasse, thereby providing participants the opportunity to comment digitally on the process and intended planning options in the period from October 14 to November 7, 2021. Further, individuals could participate in the survey not only via the *GLARA* app but also via a desktop application, and in print format. A total of 172 people completed the survey (GLARA Forschungskonsortium et al. 2021, p. 13).[2] Of the 164 responses[3], the age group of 30 to 44 years was dominant, accounting for 45 % of the participants. This was followed by those aged 45 to 59 years, accounting for 23 % of the participants. In addition, those aged between 20 to 29 years accounted for 17 % of the participants and those aged 60 years or over accounted for 13 % of the participants. It is striking that the group of younger people (19 or younger) is clearly underrepresented in the participation process, accounting for only 2 % of the participants (GLARA Forschungskonsortium et al. 2021, p. 15).

The *GLARA* app was the essential tool for conducting digital participation via AR (figure 2). It was publicly accessible and can be downloaded from the Google Play Store (Android) or the Apple App Store (iOS) to be installed on private devices (smartphones or tablets). However, no smartphones or tablets were provided to the public, which is considered a hurdle for an open participation process, as people without a terminal device and older groups of people may, therefore, have found it difficult to participate. It was also observed that the functionality of the application cannot be guaranteed on all smartphone models. The positioning of the AR display employed marker-based access, where users scanned a QR code in the form of a street sticker to calibrate the visualization. This calibration was intuitive and caused no technical problems in the self-test conducted by the authors – by focusing on the marker with the tablet camera, the calibration was completed within a few seconds.

In the AR application, urban planning options are displayed in different variants and scenarios with reference to the climatic situation in Bernardgasse *(presentation of planning content)*. Beginning from a status quo with current climate data, variables that simulate different scenarios of structural or open space planning interventions can be selected (e. g., various forms and intensities of greening, reduction of parking places) and their microclimatic effects can be witnessed (figure 3). A setting for different times of day or night and scenarios regarding the position of the sun is also enabled in the *GLARA* app. This makes it possible for the public to experience the effects of urban planning measures related to climate adaptation and their impact on the (perceived) temperature (in °C) in Bernardgasse (but the participants cannot develop their own drafts or planning options). Thus, the representations of climate data in augmented reality illustrates the effect of specific climate adaptation and mitigation measures. Through this, the effects of the planning interventions on the microclimate can immediately be experienced and the understanding of specific approaches to climate-adapted and sustainable urban development is promoted (as part of the knowledge transfer). All participants were able to evaluate concrete interventions from the same perspective.

Overall, a transparent approach to citizen participation is evident in the first participation phase for the redesign of Bernardgasse in line with sustainable urban development. In public par-

FIGURE 3: Visualization of temperature differences with and without planting in Bernardgasse, Vienna, AT, using augmented reality. Source: *www.fluxguide.com/puls/glara-kick-off-in-der-bernardgasse*.



2 Of the 172 participants in the survey, 135 people participated via web browsers, nine used the printed form, and 28 participated via the *GLARA* app (GLARA Forschungskonsortium et al. 2021, p. 14). This indicates that it was possible, in a short period of two weeks, to introduce the AR application and to actively use it in the planning process. Simultaneously, it becomes evident that other participation formats have a longer range thus far, thereby implying that AR applications should be linked with other participation tools.

3 Of 174 participants in the survey, 164 persons answered this question.

ticipation, both analog and digital formats are introduced in the participation process, both of which can complement each other in a meaningful manner. The entire participation phase was stringently organized and communicated to the residents via a kick-off event, flyers, and visibility in the public space through various information points. Thus, the *GLARA* app strongly supported the participation process and the transfer of knowledge of climate data to the population via the simulation of microclimatic effects. Moreover, within the *GLARA* app, there were opportunities for the public to participate in the survey on the participation process in order to comment on the intended plans and options. Overall, the participation process in Vienna is characterized by a combination of different approaches, both analog and digital, which complemented each other. This makes the overall participation process broader, with the aim of responding better to the disadvantages of classic formats and enabling the involvement of multilayered population groups.

Making future street design visible via augmented reality – Bahnhofstrasse and Theaterplatz in Lucerne

The case study in Lucerne, Switzerland, was a research project in cooperation with the Civil Engineering Office of the city of Lucerne and the research groups *Visual Narrative* and *Immersive Realities Research Lab* of the Lucerne University of Applied Sciences and Arts. The aim was to free Bahnhofstrasse and Theaterplatz from motorized traffic, to redesign the public space (planting 30 new trees, etc.) and to upgrade the street with an underground bicycle station that also provides a direct connection to the main station (which was rejected in a referendum in February 2022) (City of Lucerne 2022). Due to its location in the city center, the public interest in this project is comparatively high. The aim of the AR-based participation process in September 2021 was to make the various options and solutions accessible to the broad public during the planning process and to communicate with them in a transparent and comprehensible manner (Schürmann et al. 2021, p. 43).

The first plans and concepts for the redesign of Bahnhofstrasse were already developed in 2014. In 2016, an urban planning competition took place, in which various planning options for the designated area were presented. On this basis, the Civil Engineering Office developed the final plan, which was then presented to the public in September 2021 as part of the formal planning process (City of Lucerne 2022). During the preliminary considerations for the pending participation process in early summer of 2021, a private meeting took place between members of the Civil Engineering Office and the University of Applied Sciences and Arts Lucerne (on the initiative of a leading administrative manager of the Civil Engineering Office). By analyzing the *stakeholder constellation,* two aspects became decisive ones for the city administration to become involved in such a participation format. First, the open and uncomplicated attitude of individual members of the Civil Engineering Office. Their focus was on testing new technologies like AR and to see if they could offer benefits for public participation processes (the risk of failure was accepted). Second, the "strategy for shaping digital change in the economy, society, and public administration" of the Canton of Lucerne, which at least established the foundation for innovative and digital participation formats in the city of Lucerne. This gave rise to the idea of using an AR application to support the participation process and to present the intended planning in a more comprehensible and understandable manner. The use of AR at this comparatively late stage of the planning process was to present the selected planning alternative and obtain citizens' approval for it before the city council could subsequently decide on and implement this alternative (figure 4, p. 60). The discussion of other ideas or alternatives via AR was not foreseen at this stage.

After the public was informed through various media such as the newspaper, the internet and posters in public spaces, citizens were able to participate in guided tours of Bahnhofstrasse with the help of AR in September 2021 *(transparent participation process)*. The target group for the participation process included people affected by the plans and local citizens, politicians, and other interested parties. People of different ages from these groups were involved during the guided tours; this made it evident that younger people, in particular, could be motivated to participate at the guided tours through the AR-based participation. Almost 28 % of the participants were between 18 and 35 years old, 60 % of the participants were between 36 and 55 years old, and 12 % were over 56 years old (Schürmann et al. 2021, p. 47). However, compared to analog participation formats, the overall number of participants was not more culturally or socially heterogeneous.

Further, in order to be able to use the AR application, guided tours were offered by the project partners *(transparent participation process)*. On these tours, participants were provided with tablets and could use the mobile devices to virtually view new design elements like seating, bike racks, and plantings as 3D visualizations in the public space (Lucerne UAS 2021). As the project partners were in favor of simple and low-threshold access, the AR application was installed on these tablets; there was no need to download apps or register with personal data to use the application (figure 5, p. 60). In case of technical questions or problems, members from Lucerne University of Applied Sciences and Arts or the Lucerne Civil Engineering Office were available on site. The only step that the participants had to take in order to be able to see the AR representation with positional precision was to calibrate it to pre-defined markers (viewpoints). Switching between different views within the application also involved no time delay. Further, viewing different variants from different perspectives formed the heart of the AR application. Within the application, there were technical options that enabled participants to make a note of their own opinions verbally or in writing and to create their own designs. Overall, the AR application was positively evaluated by the participants in a non-representative survey conducted by the organizers in Lucerne; moreover,

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FIGURE 4: Redesign of Bahnhofstrasse, Lucerne, CH: virtual objects such as the new line of trees and seating are projected into the actual environment. Source: *https://www.hslu.ch/de-ch/hochschule-luzern/ueber-uns/medien/medienmitteilungen/2021/08/19/ar-umgebung-bahnhofstrasse*, modified.

there were no complaints regarding the technical application (Schürmann et al. 2021, pp. 47–48).

In the AR application, the redesign of Bahnhofstrasse and Theaterplatz is visualized by displaying the locations of objects, such as trees, seating, and bicycle stands *(presentation of planning content)*. The participants can switch between different display types or variants in the view. The level of detail is very high and, thus, the representation of the individual objects is rather detailed. Even the shadows are visible, thereby making the virtual objects appear even more real. Further, there is no setting for different times of day or night or weather scenarios, which could have enabled planning designs to be visualized in different lighting situations (figure 6). Nonetheless, a fusion between reality and virtuality is enabled on mobile devices. Only little negative feedback was received for participation exercises using AR applications as compared to that for analog participation exercises without digital technology. Analog participation formats often present 2D plans or renderings that participants need to understand despite lacking planning knowledge. Such images may be interpreted in different ways. However, the AR applications enabled discussions between different stakeholders about the planning content and were factual, as everyone had the same perspective on the plans or digital perspectives, thereby implying that the intended planning options were transparent for all. Thus, the representations in AR objectified the discussions among the various stakeholders. Further, unsubstantiated claims and complaints regarding planning situations, which are often otherwise made in participation processes, played no role here. All stakeholders were able to discuss concrete issues on the same basis, which resulted in dynamic discussions.

Overall, the participation in the redesign of Bahnhofstrasse and Theaterplatz in Lucerne can be considered a good example of participation in urban planning with the help of AR. According to a survey on the participation format (Schürmann et al. 2021, p. 47), the combination of using the AR application as well as having the plans and posters simultaneously available in printed form was preferred by most participants. The AR application is intuitive and easy to use. Moreover, the technology works without interference. The planning content is mapped transparently and has, thus, contributed to the success of the participation process as the technology supported face-to-face discussion of

FIGURE 5: Access to and use of an augmented reality (AR) application in Lucerne, CH (schematic diagram).

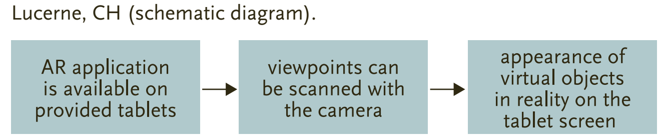

FIGURE 6: Plants and seating can be displayed as one of three variants (A, B, C), along with shading options and a playground, as virtual objects in real space in Bahnhofstrasse, Lucerne, CH, using augmented reality. Source: *https://www.hslu.ch/de-ch/hochschule-luzern/ueber-uns/medien/medienmitteilungen/2021/08/19/ar-umgebung-bahnhofstrasse,* modified.

the planning content not only among the participants but also with members from the Civil Engineering Office. However, the guided tours also “excluded” people who could not attend on the dates on which the tours took place. If the AR application had been made available on tablets and private smartphones, people would have been able to participate at any time. Furthermore, it would be helpful to integrate a participation tool into the application that not only enabled viewing but also created a collection of opinions to identify further ideas for implementation. In general, the AR application was used at a comparatively late stage in the formal planning process and was exclusively concerned with concrete design issues. However, the planning alternative itself was not up for debate due to the formal and advanced planning process.

Conclusion

The case studies in Vienna and Lucerne reveal that using AR not only increases inhabitants’ motivation to participate in planning processes but can also contribute to improving the quality of participation processes. The AR applications in Vienna and Lucerne present the planning intentions in a more realistic manner, as the concrete projects (planting of trees, creation of a cycling connection, installation of benches, etc.) are displayed in front of the actual existing background appearance. However, the extent to which AR-based visualizations – with their high level of detail, simulations, etc. – are actually better suited for participation processes than 2D plans (e.g., in the form of increased participation, more intensive discussions) was not directly analyzed in the two case studies and has not been addressed in the subsequent surveys by the project partners in Vienna and Lucerne. Nevertheless, experiences from other studies and research projects suggest that AR applications can significantly improve the quality of the participation process (see above research design).

AR applications can also be used in different planning phases. In Vienna, AR was used at the very beginning of the planning process. By presenting scenarios and options for action via AR, the intention here was to raise awareness for planning actions that might help to improve the microclimate. Here, AR is particularly beneficial as various, and occasionally conflicting, alternatives and solutions can be discussed and compared. In Lucerne, AR was used at the end of the planning process. Here, the city of Lucerne used an AR application to present the selected planning option on site (including the intended design of the public space); however, there was no discussion of the planning alternative in the AR application. Other studies and research >

projects (see research design above) similarly indicate that AR is mainly used in specific planning phases – primarily in advanced stages in the planning process – in order to visualize and, if necessary, objectify issues. Thus, the potential of AR applications in planning may not fully be exploited; therefore, in the future, the aim should be to use AR across all planning phases to visualize possible implications of individual projects in early planning phases and to make the discussion on planning alternatives more interactive and transparent.

Further, the case studies in Vienna and Lucerne and Vienna reveal that the different forms of visualization in the AR applications in Vienna and Lucerne contributed to making planning more tangible for participants. The experiences indicate that the use of AR applications, compared to analog participation formats and 2-D representations, helps to prepare the planning information for all interested parties in a visual and descriptive manner. Simultaneously, it makes the planning options more transparent, thereby implying that the AR application makes discussions among planners, politicians, citizens, and other stakeholders more objective. The Lucerne case study has shown that AR can also motivate groups that have been thus far underrepresented to participate in planning processes. However, the experiences in Vienna also indicate that the acceptance of AR as a visualization and participation tool has, thus far, been rather low compared to analog participation formats. Additionally, it was evident that AR as a digital participatory tool is not available to all users and, thus, there may be differences in accessibility and usage. Here, it must be ensured that participation processes based on AR do not lead to a manifestation of social inequalities. The combination of analog and digital participation tools may make sense here, but reliable results on this are not yet available. In any case, further research is needed in this respect, as the surveys conducted thus far tend to refer to user satisfaction with the AR application; the quality of the visualizations or the incorporating of the results in the further planning process has not yet been researched.

Nevertheless, AR applications can help ensure that sustainable development goals are given more importance in planning processes by, for example, displaying simulations relevant to urban sustainable transitions and testing scenarios or fostering interactive decision-support systems (Potts 2020, 283). This is rather evident in Vienna, where the AR application depicts the consequences of climate change for the urban neighborhood and, simultaneously, allows the selection of specific planning options (particularly planting measures) to learn how these options might improve the microclimate. By doing so, the AR application contributes to a sustainable planning process and, consequently, to sustainable urban development, because planning contents are presented in a real and transparent manner before actual construction measures begin.

In addition, AR applications also offer the potential to be linked with artificial intelligence (AI) systems.[4] New technical solutions in computer graphics, data mining and visualization, and visual and statistical analyses (Kitchin 2022, pp. 100 f.) enable urban planners and decision-makers "to tie these visual tools in with much more detailed, longitudinal, massive performance data sets to support comprehensive and useful forms of visual analytics" (Lock et al. 2019). For example, with regard to climate mitigation and adaptation, a digital twin (Dembski et al. 2020, Ruohomäki et al. 2018) could represent the digital (cross-sectional) infrastructure of the climate-neutral city and also integrate georeferenced data, real-time data (e. g., traffic flows, energy consumption), etc. On this basis, AR can be used to develop "what happens if ..." scenarios to illustrate, for example, the impact or effectiveness of individual options (e. g., shifts in traffic flows, energy savings in the neighborhood) with regard to climate protection or adaptation goals. In this vein, digital twins (as part of AI) and AR can together contribute to facilitating coordination of climate mitigation and adaptation options of different municipal departments. Simultaneously, they can analyze and evaluate sustainable and less sustainable development options throughout the entire planning process (from the development of alternatives to the concretization of partial solutions to design issues at the building level). Additionally, they can contribute to increasing the transparency and acceptance of climate mitigation and adaptation options among private actors and to improve the decision-making basis for politicians and planners. However, further empirical research and studies must be conducted in this regard, as all AR applications thus far have been developed and tested in research projects with a limited duration, thereby implying that they have not been actualized in a comprehensive, longer-term manner.

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4 For a reflection on the potential of data from smart city approaches in sustainability research see Koch et al. (2023, in this issue).

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