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Augmented Reality for Building Authorities: A Use Case Study in Austria

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Abstract: The widespread usage of BIM and technological advances in augmented reality (AR) paves the way for Construction 4.0. This digital transformation has reached the construction industry and requires consideration of all life cycle phases. The approval phase has been little researched to date. In Vienna, the analogous process takes up to 18 months. This long duration inhibits progress in the building industry. One reason for this is objections from parties who are nonexperts and have difficulty understanding the project solely from its 2D plans. Therefore, the City of Vienna wants to redesign the building authority processes through the use of BIM and AR in the BRISE-Vienna research project. This article examines possible applications for public authorities. AR can be utilised at the interface between authorities and stakeholders and is intended to accelerate processes through better communication. For the City of Vienna, 12 AR use cases were developed from process analyses and expert interviews. In addition to the conception of the AR use cases for public authorities, a study was carried out regarding their benefits and feasibility. The use cases have the potential to increase the understanding of the project for experts and nonexperts. The best-rated AR use cases (plan checking and hearing during the permission process) will be further developed in the research project. The AR use cases should help to significantly accelerate processes in Vienna and, thus, serve as a basis for other cities and countries.

Keywords: augmented reality; Construction 4.0; BIM; building authority

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1. Introduction

Digital transformation is entering more and more areas of daily life and, through new technologies, enables us to fundamentally rethink and optimise established processes. In the construction industry, this development is driven significantly by building information modelling (BIM). The central management of relevant building information in a digital model (BIM model) leads to a change in communication between the project participants. At present, digitisation focuses primarily on the phases of planning, construction, and operation. BIM methodology transforms the planning process towards integral planning [1], while project communication via a common data environment (CDE) facilitates project management during construction [2]. The central BIM model ends the media discontinuity at the interface between construction and operation, and thus creates a continuous information transfer.

However, the information transfer is not used in all phases at present, although the information gained using BIM makes it possible to design processes more efficiently across all phases of a building's life cycle. This serves as a precursor for further technologies. New technologies such as augmented reality, robotics, or 3D printing enable the use of the BIM model on the construction site and thus are essential to benefiting BIM throughout the entire life cycle [3–6]. AR is a visualisation tool for extending the real environment (existing) with digital elements (planned).

The digitisation of Austria's building sector has been thought of primarily from the perspective of the private sphere (clients, contractors, planners, etc.) and not from the public sphere (authorities). If the circle of stakeholders is expanded to include public authorities, the phases “urban design/spatial planning” and “permission procedure” should be included in the consideration. Both steps are characterised by forms of participation. Participation involves the local population or neighbours in the authority processes in these cases. Different levels can generally be distinguished (informative, consultative, or participative) [7], but they all have one difficulty in common: the use of technical language in plans and, hence, communication difficulties. Communication through plans (“plan language”) is a good form of communication for experts in the building sector but not for citizens in general. Although participation possibilities lead to good results [8], there is still the problem that some of this positive effect is achieved through high organisational effort due to communication difficulties.

An example of this is the analogue permission process in Vienna. At present, the procedure for building permits takes a very long time because the authority carries out all control tasks. The permission process for the planned building consists of many checking tasks, including consistency with all legal requirements, statics, fire protection, required lighting, the “cityscape-relevant assessment”, or the time-consuming examination of plans. In addition, neighbours can significantly prolong the procedures by raising objections, even if the complaints have no legal basis. The building code for Vienna lists all possible reasons for an objection from neighbours. These reasons include problems relating to the outer shell of the building as well as emissions. The City of Vienna would like to counteract this by digitising. Therefore, they started the research project BRISE-Vienna. This project aims to reorganise processes by integrating openBIM and AR. This paper was written within the framework of this research project. The time consumed by verification can be reduced using automatic verification rules [8] that check the openBIM model. The involved parties have different knowledge of building law, and various interpretations or ideas arise based on existing documents. New digital technologies (openBIM and AR) enable better and clearer visualisation and, hence, a better understanding of the planned building. For this reason, fewer objections and a reduced time for the building permit procedure are expected.

Therefore, this paper’s central research question is as follows: “How can the use of AR help in the digitisation of building authorities”? To answer this question, in the BRISE-Vienna project, the authors analysed the situation of the City of Vienna, identified potentials for the use of augmented reality, and defined specific use cases. The aim of this paper is to present these AR use cases developed for building authorities in order to reduce process time and increase understanding of the project.

Through the digitisation of the administration, political decision-makers hope for significant improvements in these areas. Research results regarding the use of augmented reality as an alternative to 2D plans among experts [9] support the hypothesis that a positive effect achieved can also be transferred to nonexpert persons and is perhaps even more pronounced among this group.

2. Methods

The methodology consists of four phases and two core methods: process analyses and stakeholder interviews. Figure 1 displays the step-by-step procedure with the sequence of individual phases (from bottom to top). The steps within the phases are shown from left to right (definition of the respective goal, the applied methods, and the results). As a basis, several articles with literature reviews were studied. In the second phase, the authors held initial discussions with representatives of the authority, identified stakeholders, and documented existing processes. Based on this, weaknesses and possible connection points with AR were identified. From these analyses, the authors formulated initial use cases and discussed these with stakeholders in Phase 3. Existing use cases were further developed, and new ones were defined in the interviews. Finally, the authors summarised the AR use cases in the chronological sequence of the authority processes. The collected data were continuously evaluated according to the principle of thematic analysis [10].

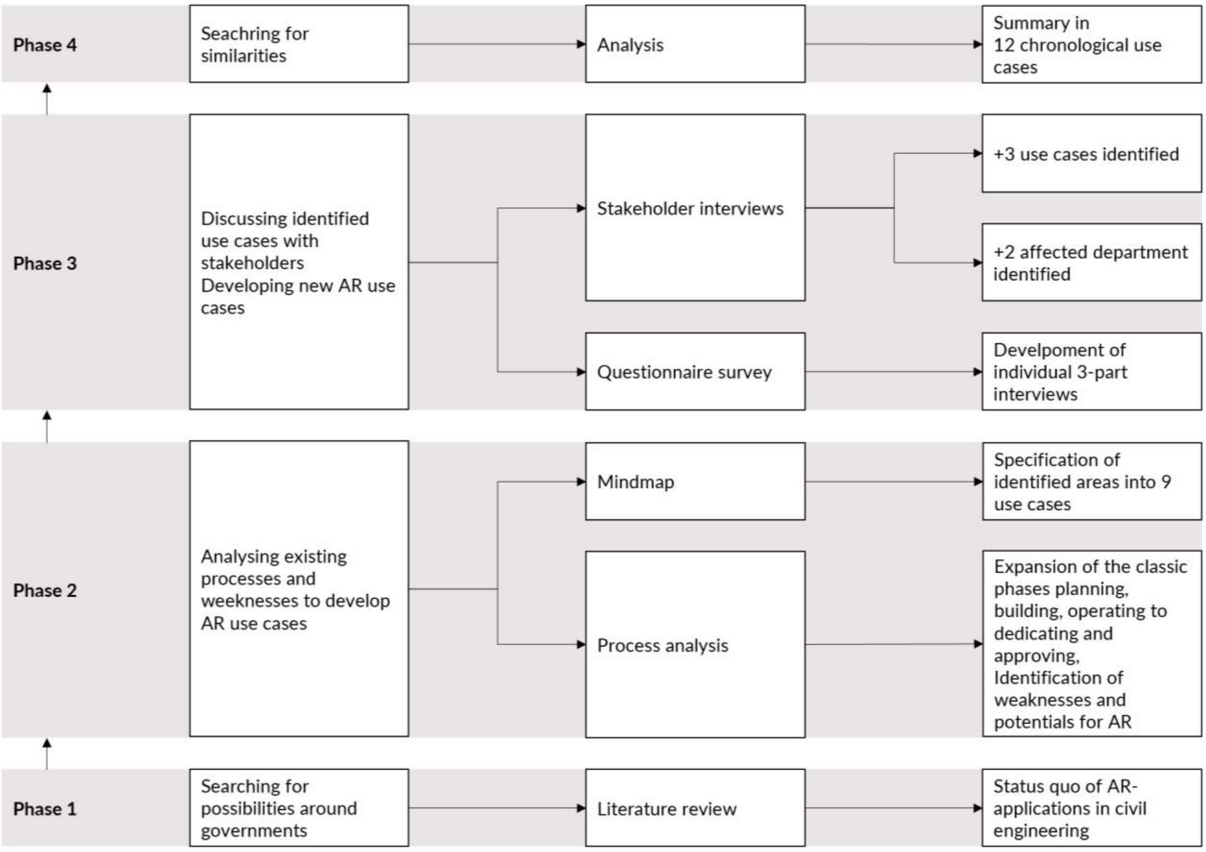

Figure 1. Research method consisting of four phases: literature research, process analysis, questionnaire, and final analysis.

2.1. Phase 1—Literature Research

In a survey on the status of augmented reality applications in the construction sector in Austria [11], the authors found that current applications mainly concern the construction and planning phases. The focus of most use cases to date has been on the construction phase, followed by the construction preparation, planning, and operation phase [12]. Upon further consideration, five main topic areas can be identified [13,14]:

- Stakeholder engagement;
- Collaboration/communication/design support;
- Construction management/documentation/quality control;
- Safety management;
- Facility management/operations and management.

In the field of Construction 4.0, the BIM model, as a data basis, is often a requirement for new technologies. While VR is a suitable technology for the planning phase, AR is preferred for the construction phase for on-site usage, as a site extension of BIM [15]. AR applications can be divided into two types, depending on the hardware used: immersive and nonimmersive [1]. Immersion is defined as follows: "a state of deep mental involvement in which the subject may experience disassociation from the awareness of the physical world due to a shift in our attentional state" [16]. This state is created using head-mounted displays (HMD devices). In contrast, the effect of AR applications on mobile devices (mobile augmented reality (mAR)) is much smaller, i.e., not immersive. Mobile devices offer the great advantage of being available everywhere at a low cost. Applications for mAR are often geared towards the design and preconstruction phases, as no exact location or superimposition is necessary. However, advances in software and technology in recent years have increasingly led to the development of AR applications for quality management during the construction phase [17,18]. The improvement in tracking systems allows for a stationary overlay of a digital model with the construction state during the use of mAR.

Compared with mAR, AR glasses offer the advantage of having a more immersive impression [6]. The hands-free option also extends the range of applications to training (e.g., welding), safety training [19], or maintenance work [4]. At present, AR is mainly used in the construction industry for the inspection of the built construction on-site, e.g., for the inspection of steel columns [20], defect management [6,21,22], or concrete and masonry embedment [23].

However, the tracking accuracy decreases with movement in the building. This tracking inaccuracy and the costs, which are still very high, hinder the widespread use of HMDs [24]. Although a wide variety of technologies are being tested (such as SLAM or enhancements using laser projection [25,26]), there are still challenges in overlaying virtual and real elements. The tracking accuracy decreases with movement in the building. The deviation, known as drift [27], does not yet allow for the application of AR in some sectors (e.g., reinforcement acceptance).

The authority processes, particularly when occurring as an interface between planning and construction, have been little researched to date. The potential of both AR technologies (HMDs, mAR) within this phase is investigated in Phase 2.

2.2. Phase 2—Process Analysis

In the first phase, the potential of AR in the public authority procedure was generally determined. Based on this, the second phase focused on identifying possible points of contact. The analysis was carried out in three steps:

- Identification of the participants;
- Identification of the processes;
- Identification of process weaknesses (points of contact).

Consideration from the authority's perspective required splitting the life cycle consideration into further subitems. The phases of planning, construction, and operation were supplemented by the phases of "zoning" and "permission". Different departments within the authority carry out the tasks in these phases. Five key departments were identified and defined as stakeholders for interviews based on the permission process (see Figure 2). These departments are responsible for zoning (ZO), surveying (SU), architecture (AR), building authority (BA), and the fire department (FD).

The zoning phase deals with spatial planning and urban design. The basis for this is the zoning and development plan. This regulates questions of building density, building height, and building mass distribution. In Vienna, citizens can participate in preparing a zoning and development plan. Vienna offers different forms of participation for them. Based on these possibilities, three AR use cases were developed.

The planning is carried out by planning offices. The basis for the planning is a surveying plan prepared by a surveyor approved by the city. An AR use case was developed for the city's surveying department.

One phase that has seldom been considered in current BIM projects regarding the new possibilities they offer is the building permission process, referred to as "permission" in the following. Understanding the plans is often a hurdle for nonexpert persons and increases the length of procedures. Four use cases for spatial visualisations using AR aim to counteract this.

The end of the construction phase is indicated to the authorities by a completion notification to the authorities. Currently, checks of the building consensus are mainly carried out in the building authority's office based on documents. AR could enable object-based on-site plan checking in the future.

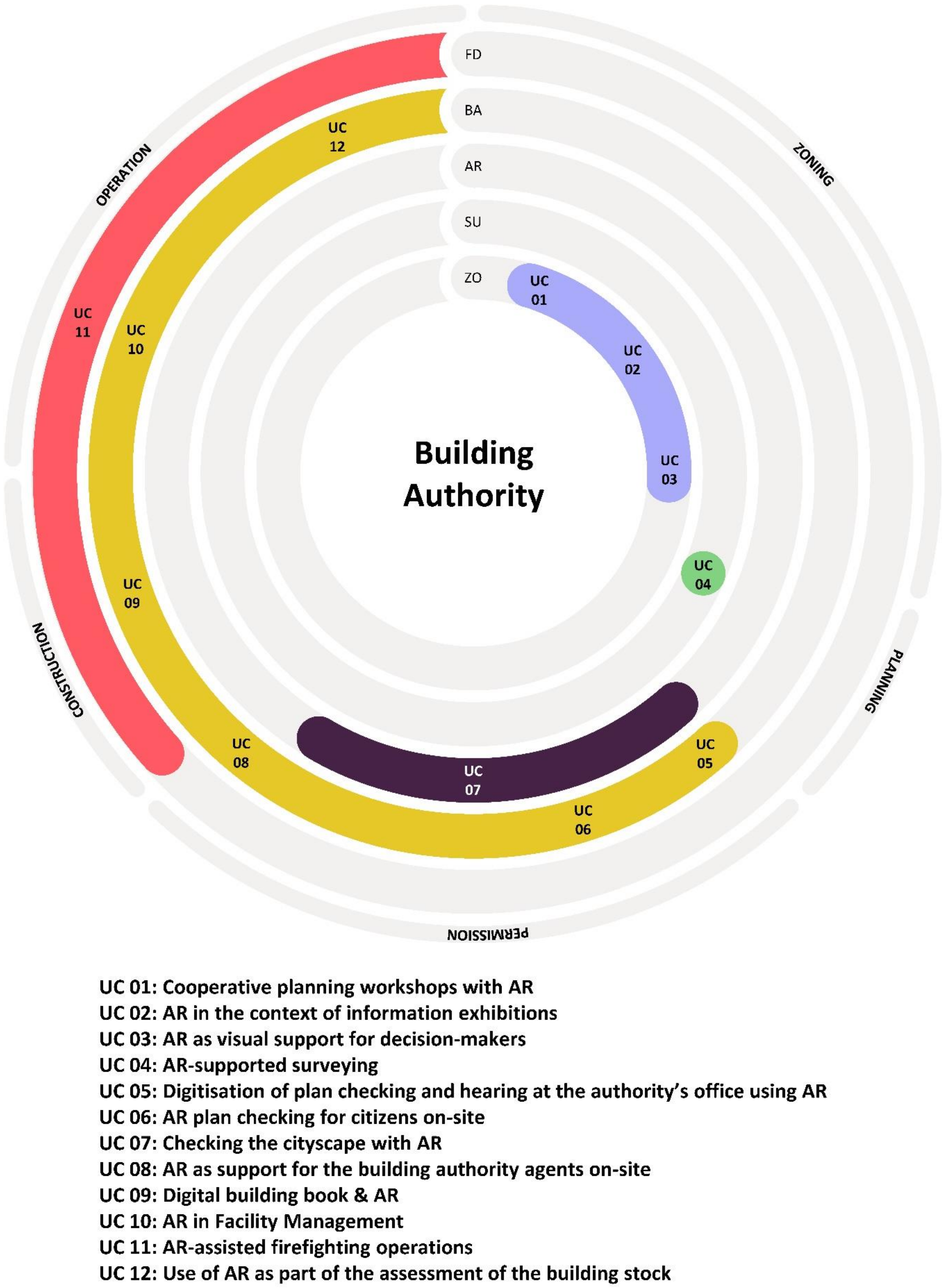

Figure 2. AR use cases during the life cycle of the building concerning the building authority. The colours highlight the different stakeholders.

In recent decades, the documentation of maintenance measures has only been available in paper form. Although the planning is already digital, this documentation is still paper-based. This is a media break of information from digital to analogue. In Vienna, this documentation is regulated by law with the creation of so-called building books. A building book documents inspections of various components carried out in due time and, thus, identifies deficiencies in time. In this context, the potentials arising from introducing a digital building book in combination with AR are discussed.

The investigated processes reflect the situation in Vienna. The situation in Vienna is characterized by a strong emphasis on participation, which is rare by international standards. However, the presented processes can be used as a basis to improve participation and allow for digital transformation.

2.3. Phase 3—Stakeholder Interviews

Following the process analysis, the results were validated through interviews. In the research project BRISE-Vienna, the project partners included all stakeholders in a building authority process. These included representatives from the different sections of the building authority, BIM experts, and the association of architects. The different perspectives and insights from practice were integrated into the process. Among the project partners, all affected stakeholders were invited to interviews. In these interviews, existing use cases were further developed, and new ones were defined. The interviews consisted of two parts: a qualitative section to collect and discuss different approaches and a quantitative section to survey the potential of the developed ideas.

The interviews were conducted with people with different levels of knowledge about AR. Depending on the level of expertise about AR, the persons received introductions regarding AR (delimitation of the topic and examples). The AR examples showed potential for its use. The aim was also to create a common knowledge base to identify common points of contact with AR, both to stimulate the participants' thoughts and to help define new use cases.

The qualitative section was followed by presentation of previously developed ideas for AR use cases with joint discussion and further developments. This led to the documentation of new ideas for potential AR use cases. A quantitative survey of the potential of the individual AR use cases was conducted in the second part of the interviews. The experts rated the added value of the previously discussed AR possibilities in a five-stage scheme from "very high" to "very low".

Fourteen different representatives from five different sectors were interviewed (see Table 1). Due to the restrictions during the COVID-19 pandemic, the interviews were conducted as online meetings or via mail exchange. The average interview duration was about two hours.

Table 1. Interviewed stakeholders and their professions.

Participant	Area	Profession
1	District planning and zoning	Civil servant
2	District planning and zoning	Civil servant
3	Architecture and urban design	Civil servant
4	Building authorithy	Civil servant
5	Building authorithy	Civil servant
6	Building authorithy	Jurist
7	Building authorithy	Civil servant
8	Geo-information, 3D-modeling	Civil servant
9	Innovation	Civil servant
10	Photogrammetry	Civil servant
11	Survey, Innovation	Civil servant

Table 1. *Cont.*

Participant	Area	Profession
12	Photogrammetry, 3D-modeling	Civil servant
13	Architecture	BIM operation management
14	Architecture	BIM operation management

2.4. Phase 4—Analysis

A total of 21 use cases for AR applications were identified. Then, 12 use cases with the highest probability of implementation were selected by authors and stakeholders. For these 12, the authors developed general process flows. When there were several possible ways of meeting a need (e.g., plan checking: at the building authority level, on-site, or online), these were compared in terms of their benefits for different target groups, their requirements, and their challenges.

3. Use Cases

The result of this evaluation was an overview graphic of possible AR use cases for public authorities in the context of digital construction projects (see Figure 2). The structure of the figure is based on the chronological process flow. The use cases are classified clockwise according to the five phases under consideration (zoning, planning, permission, construction, and operation). The use cases are also colour-coded in rings and assigned to the five main stakeholders. Here, too, the arrangement is chronological, according to their occurrence in the overall process, from the inside to the outside. The individual use cases are explained below in sections corresponding to the phases. Use cases 05 (digitisation of plan checking at the authority's office with the help of AR), 06 (AR plan checking on-site), and 08 (AR as an on-site support for the building authority agent) have already been dealt with in detail by the authors in [28], and are only briefly summarised here.

3.1. Zoning

The aims of "smart cities" place new demands on urban development. A central goal of a smart city is to strengthen social coexistence, e.g., through participatory opportunities for the citizens [29,30]. In Vienna, citizen participation has been implemented in an exemplary manner for a long time. It is to be further expanded in the future through the use of new technologies (e.g., digital participation platforms) [31]. The integration of AR thus follows a central goal of current urban developments to promote cooperation between administration and citizens. Currently, the members of the public already have the opportunity to help shape the future appearance of the city by participating in spatial planning. Spatial planning in Vienna is regulated by the zoning and development plan. This plan governs the building possibilities of plots of land (above all, the building density and structure) using graphical representation and textual additions.

The zoning and development plan serves as a legal basis for architects in planning, as well as for the departments of the building authority for the examination of planned building projects. The process of deciding on the zoning for a new district can be divided into five steps [32] (see Figure 3): The process starts with the idea (Idea). Subsequently, the framework conditions are ascertained (Clarify), and concepts are developed on this basis (Planning). Before the spatial planning is decided (Zoning and Resolution), the opinions and objections of various stakeholders and the population are obtained and examined. Building on this process and existing possibilities for participation [32], the authors developed new opportunities for participation using AR. The use cases are described below.

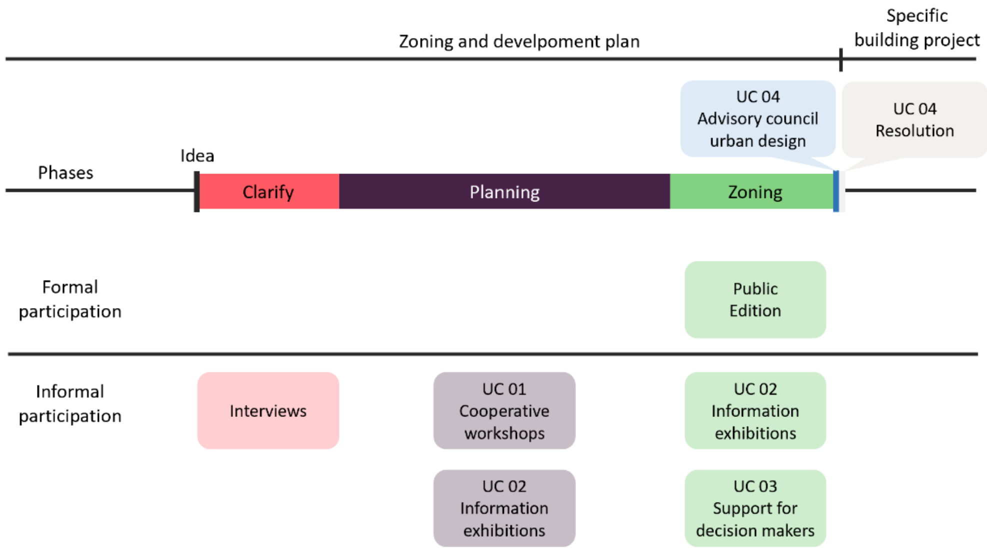

Figure 3. Single steps of the process of deciding on the zoning for a new district with new AR use cases.

- UC 01: Cooperative planning workshops with AR

Before urban planning competitions are announced, public planning workshops can be held. In this format, ideas for urban concepts are developed cooperatively with citizens, local actors, initiators, and politicians. This phase aims to collect and analyse the stakeholders' needs and summarise them in target definitions as a basis for planners. The existing process can be extended through AR and the gamification principle in this early development phase. Gamification describes the increase in intrinsic motivation to solve problems by using gaming elements in a new context [33]. Finland has already tested this approach to designing public spaces using virtual reality [34].

Augmented reality is mainly used for the visualisation of existing plans. However, in the development phase of spatial planning, BIM models do not yet exist. In this case, AR can be used to develop rough spatial structures. Building mass distribution considerations can be made using a modular system with various predefined elements, and effects such as shadowing can be simulated and visualised with AR. Positioning, orientation, and the height of buildings have a decisive influence on the lighting issue: the lighting situation of rooms depends on neighbouring buildings and the shading of public areas. The limitations of inner-city temperatures and the avoidance of urban heat islands (UHIs) will become more critical in the coming decades [35,36]. Intelligent spatial planning concepts can achieve a cooling effect similar to that of tree planting.

The placement of solids can indicate the division of residential and industrial areas or green spaces (see Figure 4). Using parameterisation, information on the number of dwellings or workplaces created is directly displayed. The developed concepts then serve as input for urban planning competitions.

- UC 02: AR in the context of information exhibitions

If urban planning concepts are already available, information exhibitions can be held. In Vienna, information exhibitions provide the public with information on the status of current district planning. To date, plans, scale models, or other visualisation concepts have been used with the disadvantages of high costs (scale models) and nonexpert citizens struggling to understand the technological aspects of the plans. By using AR, for example, a virtual spatial model of the district could be obtained via a QR code on an information poster and viewed on a tablet or one's smartphone. If there are several design drafts, they can be cost-effectively and efficiently displayed and compared with each other by overlaying them. In terms of presentation, two variants are interesting: a combination of a haptic model with a virtual supplement or an utterly virtual presentation. In the first case, a cardboard or 3D-printed model of the spatial planning area (surroundings) is supplemented by a virtual overlay of the different planning drafts. This involves costs for the hardcopy model but provides citizens with easily understandable information. In the second variant, the entire representation is virtual. This can save costs, but investigations regarding suitability are recommended, especially for older people.

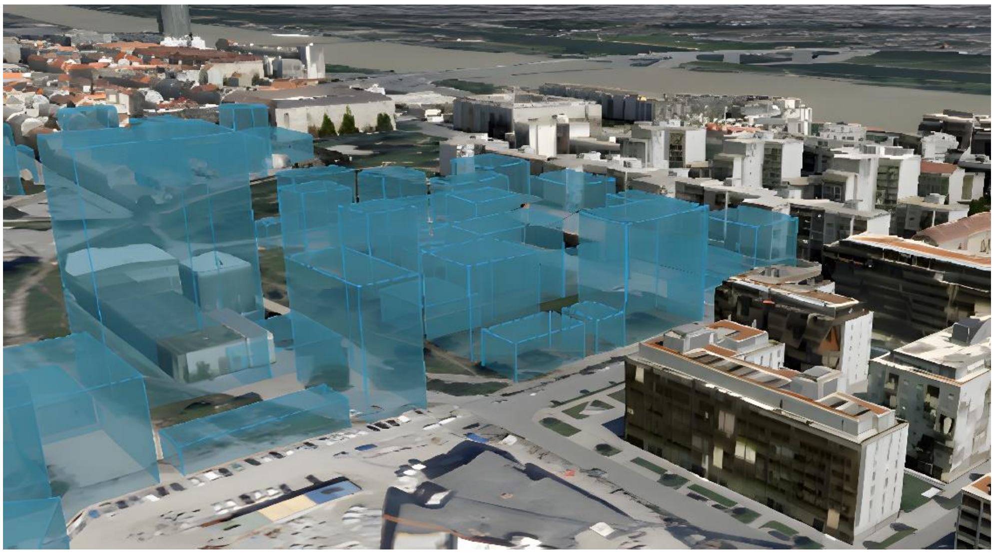

Figure 4. Development of a new area. AR representation of the building mass distribution (source: City of Vienna).

- UC 03: AR as a visual support for decision-makers

Augmented reality can support decision-makers in various phases, and the advantages of AR increase with the level of detail (planning progress). In the development phase of spatial planning, work is completed using designs with a low level of detail. In this context, AR can, for example, support juries of urban planning competitions or political decision-makers as a visualisation tool. With the implementation of an evaluation tool, designs could be assessed and feedback obtained for planners and decision-makers. The feedback from the citizens, collected during the information exhibition, can then be integrated into the decision-making process.

After a decision is made regarding the development plan, AR can also be used in architectural competitions for public buildings. Currently, building permissions in Vienna are exclusively established in analogue form. As an additional supplement to the planning documents, scaled models are often required but only used for architectural competitions. However, if produced only for this purpose, these models are very time-consuming and correspondingly expensive to produce. In the BRISE-Vienna research project [37,38], the building permission process is currently being developed on an openBIM basis for the City of Vienna. The development of the openBIM building permission process will make spatial digital building models available early in the planning process. With the help of AR, these could be used for digital visualisations instead of physical models and without additional costs for comparing different designs. The digital building models only need to be exported from the authoring software in an appropriate format (IFC or OBJ) and loaded into an AR viewer.

3.2. Planning

The use cases presented in the previous section are independent of the projects as part of the development of the zoning plan. In the next step, the focus is shifted from the superordinate level to the project-specific level. The building regulations in the zoning plan can be used as a basis for preliminary design planning. Due to the high requirements for dimensional accuracy during the objection process, the City of Vienna requires the preparation of a surveying plan. During this practice, the alignment lines are precisely located and subsequently checked by the city's department.

In [8], the authors described the current analogue permission process and developed a digital openBIM-supported process based on the prevailing disadvantages. Part of this process is the surveying plan. This contains alphanumeric information from the zoning plan (e.g., property number, zoning, or building class) and geometric information from the on-site survey in the form of lines (e.g., alignment lines) and areas (e.g., building site, existing buildings, or roads). The surveying plan serves as a planning basis for both the BIM model for architects and checking the BIM model for the authorities. At present, the surveyor measures prominent points, transfers them to CAD software, connects them to lines and surfaces, and finally provides them with alphanumeric information. A visual overlay and check of the surveying plan with the real building site is only possible with AR (overlay of virtual elements over a real environment). This could represent an additional module for quality assurance in the future. Based on these results, an AR use case was developed to create the surveying plan and check a so-called reference model (REM) within the future openBIM-based permission process.

- UC 04: AR-supported surveying

Within the future openBIM-based permission process, the surveying plan is only an intermediate step. A reference model (REM) is automatically generated from the surveying plan and additional information is generated from the building design to verify the BIM model. The REM can be understood as a kind of 3D development plan of the construction site and the neighbouring buildings, which is required for the automated verification of a site's buildability, correctness of position, and information details [8]. The basis for the REM is the legal material and the surveying plan in IFC format, consisting of spatial lines and areas and including additional information in the form of attributes.

As a first step, AR could help to create the surveying plan and check the REM. In this case, AR in combination with an HMD can be seen as an alternative to computers and CAD software. After transferring the survey data (point cloud) to the HMD, the individual points could be connected to lines and surfaces using AR. When entering alphanumeric information (e.g., defining a line as a building line), the zoning plan is displayed as a base layer. A possible interface is shown in Figure 5.

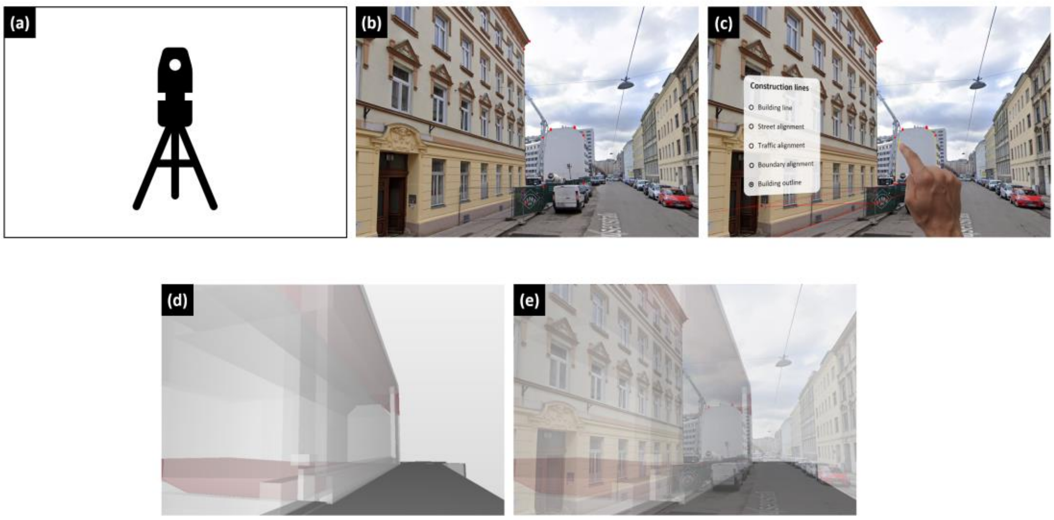

Figure 5. Process steps from surveying plan to controlling of reference model: (**a**) surveying the construction site, (**b**) visualising surveying points with AR glasses (HMD), (**c**) creating the surveying plan using HMD, (**d**) generating the reference model, and (**e**) controlling the reference model using an overlay of the reference model with reality.

In a second step, AR could create a quality assurance tool for the REM. Once the surveying plan has been made, the REM can be generated based on this. This makes it possible to conduct a plausibility check of the REM with AR. Errors in the input of the surveying plan or the generation of the REM can be detected visually. AR thus represents a two-stage quality assurance tool for checking the survey results and the REM.

3.3. Permission

In the next phase in the building life cycle, the building authority reviews the permission documents. In the future, building permits in Vienna can be issued digitally based on a BIM model, once the planning has been completed based on the surveying plan. These BIM models enable the extension of the permit review to include AR applications [28], especially in the area of plan checking. In Vienna, this plan checking not only includes checking compliance with all valid legal materials (zoning, building regulations, etc.) but also protecting the interests of neighbours [28]. For this purpose, the authority examines the objections of neighbours as defined in the building code. In addition, neighbours can inspect project documents during the permission procedure to check for compliance with their objection options and, if necessary, raise an objection. At present, 2D plans are used for plan checking. The technical language of the plans requires spatial understanding and can lead to a feeling of a lack of transparency among nonexpert persons. Based on these problems, an AR app was designed to digitise the plan-checking process and is currently being tested. In addition to an adapted process for plan checking at the level of the authority, this concept also includes the possibility of plan checking on-site. Both use cases are described in detail in [28].

- UC 05: Digitisation of plan checking and hearing at the authority's office using AR

An AR model consisting of two partial models is used for the citizens' plan checking with regard to the authority. The submitted BIM model is reduced to the relevant information for the plan checking of the citizens and then inserted into a digital as-built model of the city (see Figure 6). The objection rights of neighbours concern the building envelope. The reduction of the BIM model submitted to the building envelope thus corresponds to the legal situation. Additionally, this protects the client's privacy and the planner's intellectual property.

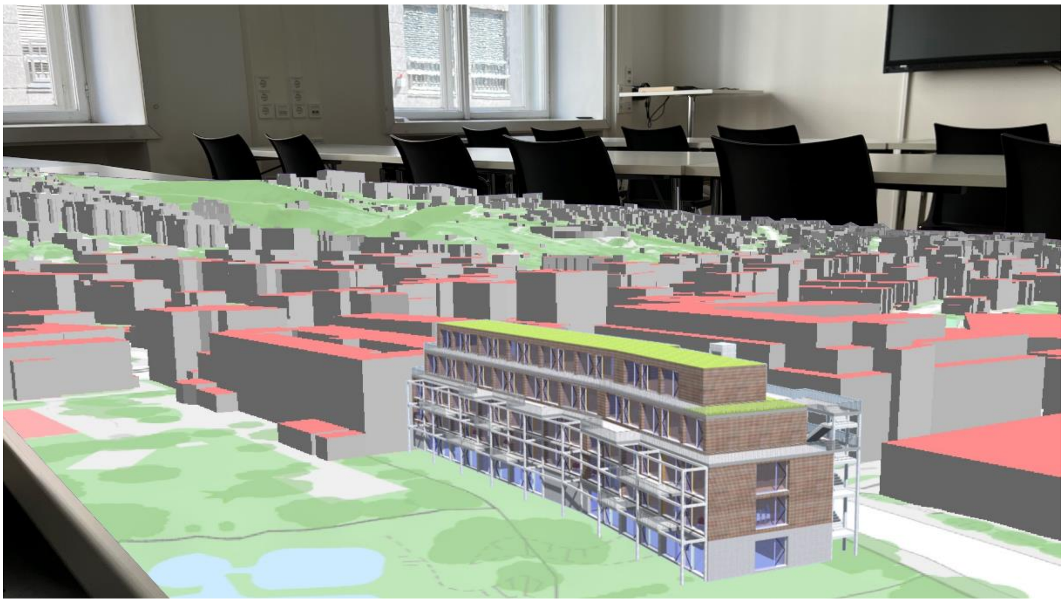

Figure 6. Overlay of a building application model with a 3D city map.

The data basis for the as-built model is provided by airborne laser scanning and terrestrial surveying [39,40]. The data are combined into a 3D geodata model with abstracted building bodies to capture the existing buildings. This data collection method is associated with inaccuracies of up to ±25 cm. These data are currently only collected at 2-year intervals; therefore, they are not guaranteed to be up to date at the time of submission. The data collection regarding the neighbouring buildings in the surveying plan enables comparison and, thus, ensures future data's accuracy.

Subsequently, the two submodels are converted into a common model in an appropriate format for visualisation with AR (JSON). The spatial representation of the submitted building project, including neighbouring buildings, using AR helps improve the understanding of nonexpert citizens during the plan-checking process.

The same AR model can also be used for the hearing process. In Vienna, at the end of the standard permission process, the authority can hold a hearing with the parties involved. The hearing takes place at the authority's office after the plan-checking phase. The basic idea is the same: instead of plans, the meeting is supported by AR visualisation. For this purpose, each participant receives their own tablet. With this tablet, everyone can view the AR model from their own perspective. In order to improve communication, the tablets can be synchronised. When synchronised, in the AR model, the building authorities official can select and highlight specific components which are displayed on all the tablets. This helps the participants to follow the explanations.

- UC 06: AR plan checking for citizens on-site

In contrast to the plan checking that occurs at the building authority level, the submitted BIM model is not embedded in the digital as-built model of the city but is displayed on-site, directly between the neighbouring buildings. The submitted building is located using a vector (defined by two points) and then visualised in the correct size and position [28]. Thus, the use of AR also enables forms of participation for citizens.

At the same time, however, access for citizens imposes high requirements concerning authorisation questions. If not only participating persons but citizens in general are given the possibility of access, a new concept of information access is required. A possible starting point could be an online city map in combination with AR geotags.

The City of Vienna offers an unrestrictedly accessible city map based on the data of ViennaGIS [41]. In this map, different kinds of information can be accessed via different layers (e.g., short-stay parking zones, markets, hiking trails, and drinking fountains). This website could be extended with layers for public building projects, e.g., AR models linked by geotags. Geotagging or georeferencing is the process of linking geographic metadata with other digital data (e.g., texts or images) [42]. The result of the process (the link) is a geotag. In this case, the tags contain links to call up the corresponding AR models. If the link is called up, authentication takes place via a digital signature on the mobile device so that the user's identity is established. This is followed by a comparison with the access authorisations of the building project in the city's database. After successful authentication, the AR model is viewed.

- UC 07: Checking the cityscape with AR

This form of on-site representation can be used by both citizens and authorities. In Vienna, the permit process consists of many partial inspections, including statics, fire protection, required lighting, or the "cityscape-relevant assessment". The latter focuses on checking the integration of the building project into the townscape from an architectural point of view. This often requires on-site plan checking. The virtual representation of the planned building project amid the actual neighbouring buildings offers considerable added value when preparing the expert opinion. The entire process can be carried out on-site using tablets.

3.4. Construction

In the future, the openBIM permission process will enable a different approach to the creation of a digital twin of the City of Vienna. Due to the increasing number of digital submissions, digital abstracted models of existing buildings based on measured data can be continuously replaced by accurate BIM models. The digital twin of the city, which is becoming more and more precise, can serve as a basis for various applications. These include building physics simulations (summer overheating of cities, energy efficiency, etc.), urban mining strategies, or the application of AR, such as for checking the building stock or as a support for the fire brigade [43].

The authority aims to ensure a safe and proper construction process. Whereas new construction projects focus primarily on building consensus, safety questions are often clarified in existing buildings. This must be regularly checked by a building authority agent. AR can support building authority agents in several ways. Their tasks require on-site inspections on the construction site or in the existing building. AR glasses are particularly suitable for this purpose.

- UC 08: AR as support for the building authority agents on-site

The tasks of the building authority agents cover the construction and operation phases. One task of a building authority agent is to check the building consensus regarding the approved building plans/models. These inspections can occur during or after the construction work's completion. Due to the high cost of on-site plan checking for all construction sites (e.g., familiarisation with the project, orientation in the building, and dimensional checks through manual measurements), these are randomly carried out during construction. After the completion of construction, a notification of completion must be submitted to the authorities. In this notification, a civil engineer confirms compliance with the building permit. The inspections refer to the submitted documents focusing on building projects that have already shown conspicuous issues during construction.

Establishing an openBIM-based building permit in Vienna will enable future on-site plan checking using AR, which can occur both during construction and after completion. The basis for these checks is the BIM model submitted as part of the application for a building permit. The content of the assessment is the entire architectural model, which is superimposed on reality, and deviations are checked, documented, and reported. This type of review currently requires a great deal of familiarisation time. The orientation and review on the construction site are carried out based on the submitted plans and are often very time-consuming. If equipped with an HMD, the process could be easier for building authority agents. In the field of vision of the glasses, for example, a small floor plan, which marks the current position, can help with orientation in the building. Plan checking can be facilitated by overlaying the actual state of the building with a semitransparent representation of the BIM model. A measurement process is no longer necessary to determine whether elements (e.g., walls) are in the intended position. Current deviations in the location offer sufficient accuracy for this case [24]. Differences can be quickly identified, quantified using a measurement feature, documented in the BIM model through screenshots, and referenced to the building component on-site. Future deviations could be detected and displayed in AR [3]. At the authority level, the detected deviations are evaluated and summarised in reports. Depending on the severity, a request is made to the owner (e.g., adjustment of the digital model or adjustment of the real object required). The documentation can be exported as a BIM Collaboration Format (BCF) file for forwarding to the owner.

3.5. Operation

In Austria, the building authority has various tasks during the operational phase of a building. In this phase, multiple tasks can be simplified through AR support.

- UC 09: Digital building books and AR

The random checks conducted by the building authorities could be used not only to verify the building consensus but also to check building safety based on the digital building register. In Vienna, operators must ensure safe building conditions according to legal regulations. For this purpose, the building regulations mean that a building register must be kept. This must contain the following pieces of information, among others [44]:

- The designation of the components that require regular inspection;
- The date of the initial inspection and future intervals;
- The results of the checks that are carried out.

National standards [44] suggest relevant components, including inspection intervals in the form of checklists (e.g., an annual inspection of the roof truss and a monthly functional check of the ventilation of staircases). Although building logbooks are currently digitally created (in Excel or with special software), they are kept in paper form in the building for inspections (for the building authority). BIM models will enable the model-based documentation of these data in the future.

At the time of submission, this information is not yet available (LOI 300). Therefore, the review during construction was limited to the architectural model, as described in UC 08. Only in execution planning, awarding, and construction was the required information continuously entered into the BIM model. The resulting as-built model (LOI 500) was transmitted to the authorities after the completion of construction. This digital model was the basis for the AR use cases' facility management (FM) and safety (firefighters).

An inspection of nonapproved construction measures (e.g., additions) or the control of the building book could be carried out in the future using HMD devices. During an inspection, the BIM model (LOI 500) overlaps the existing building. Structural deviations can thus be easily detected and documented. Information on the most recent inspections and required inspection intervals is displayed in the field of vision.

An as-built model, in combination with AR, can make processes more efficient for FM. With AR, for example, information can be transferred to the BIM model and kept up to date.

- UC 10: AR in facility management

The operation phase is the most significant life cycle phase, in terms of both time and costs. This phase is also interesting for cities as operators of public buildings. In Vienna, the city manages 1613 buildings through the building management department/MA 34 authority [45]. The operating phase accounts for up to 70% of the life cycle costs (LCCs) [46]. The currently poor data transfer at the interface between construction and operation leads to cost factors, e.g., [47]:

- FM managers need up to 20% of their working time to search for information (up to 70% savings potential);
- High time expenditure for mass determinations (up to 70% savings potential).

The maintenance of digital twins based on BIM models can help to reduce these costs. The focus here is on the transfer of digital data from construction to FM (BIM2FIM). Before linking information from the BIM model to CAFM software, the information must be stored in the BIM model. Augmented reality can support this process.

During progressive BIM-based planning, the information content of the digital model is constantly increasing. In building services, initial dimensioning and simulations are carried out, and components are optimised before the tender is issued. Product-independent performance requirements are finally put out to tender at the end of the planning phase. In the construction phase, the companies commissioned select suitable products based on the tender documents and install them. After the construction is finished, all important building parts for facility management are identified using a QR code or RFID. The LOI 500 required for many FM tasks requires transferring product-specific information into the digital model. This step could take place during the HVAC acceptance process. In the AR-AQ-Bau research project [6], an AR-supported acceptance of building service components using the AR glasses Microsoft HoloLens 2 was developed for maintenance work during operation [4]. The possibility of transmitting manufacturer information (e.g., performance and warranty data) using QR codes and AR glasses according to the BIM2QR principle was also explored. While recording defects, QR codes on installations could be scanned using AR glasses, and manufacturer information could be retrieved and stored in the BIM model using gestures. The data from the BIM model could then be linked to CAFM software. In addition, step-by-step instructions can be called up, or an expert can be consulted via a remote system.

- UC 11: AR-assisted firefighting operations

Firefighters are exposed to many hazards during operations, including high temperatures, smoke poisoning, or falling parts, with the most significant danger being smoke. The reduction in risks for firefighters is the focus of the research project ProFiTex2 [48] (see Figure 7) and the system C-Thru by Qwake Technologies [49]. In fires with heavy smoke development or darkness, the field of vision of the emergency services personnel can be almost entirely restricted.

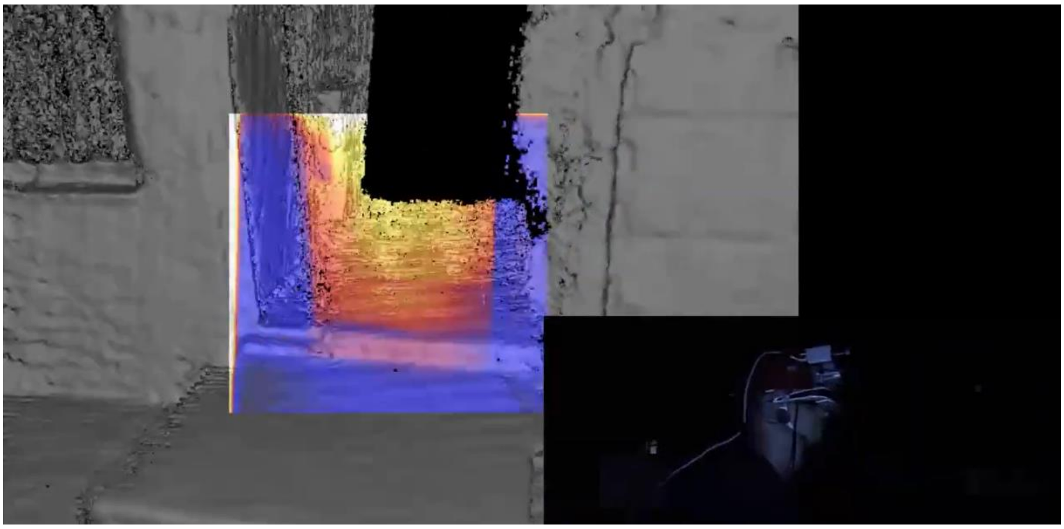

Figure 7. Firefighter's point of view with thermal overlay [40].

Qwake Technologies has developed a two-component system consisting of AR glasses for the emergency forces and a remote coordination system. Using AR, the real environment can be overlaid with orientation information. The environment can be scanned via the infrared sensors of the AR glasses, and a spatial model can be generated. The recorded data of the point cloud are evaluated, and only edges are projected into the field of vision of the AR glasses. This digital information enables emergency forces to orientate themselves despite severe visual restrictions due to darkness or smoke. In addition, the system can be supplemented with thermal sensors to detect critical temperature ranges (see Figure 7).

The second component is remote coordination. A bidirectional exchange occurs between the components; the field of vision of the emergency forces and the location are transmitted to the control centre and the control centre sends, e.g., navigation instructions to the emergency forces. At present, no building plans are available to the fire brigade in case of an emergency. The emergency forces have to orientate themselves in the building and correctly assess sources of danger. In the future, digital building models, which are available to the authority through the permission process, could support navigation within the facilities. The operations coordinator loads the submitted BIM model. This provides floor plans as well as material information regarding the building fabric. In combination with the live images of the emergency forces, the coordinator can, thus, better assess potential hazards and transmit information to the emergency forces, e.g., the remaining deployment time due to the fire resistance class of the building structure, the risk of falling components due to the component structures, priority rooms due to the rooms' designations, or instructions for navigation in the building due to the floor plans. The transmission of the BIM model to the individual emergency forces for superimposition onto the actual situation using AR glasses is not reasonable in this scenario. The BIM model in the LOI 300 has too little information for pure orientation in limited-visibility conditions, as furnishings are not included.

- UC 12: Use of AR as part of the assessment of the building stock

Another task of building authority agents is the assessment of damage in existing buildings. For example, after a fire, the fire brigade notifies the building authority to check the structural situation and determine whether there is a danger of collapse. For this assessment, it is essential to understand the static concept of the corresponding building. The use of AR can also provide support in this case. The real building condition is overlaid with the digital BIM model. By selecting individual layers, it is possible to display only load-bearing components (feature: load-bearing = true). In this case, the real environment is overlaid with the statically effective spatial model via the AR glasses. Supported by this overlay, building authority agents can quickly recognise the load-bearing structure. AR could, for example, help identify which cladding levels need to be removed to assess the statically relevant component. This workflow means that inspections of the as-built plans on-site are no longer necessary.

4. Discussion

This case study shows the variety of AR and building information modelling (BIM) applications for public authorities. The potential and feasibility of the use cases were also assessed through stakeholder interviews. The authors used 4-part scales ranging from 1, “very helpful”, to 4, “obstructive”, for potential and a, “directly implementable”, to d, “implementable within 10+ years”, to assess feasibility. The results and the authors’ assessments were summarised in an evaluation table (see Table 2). The hardware that is used plays an important role. Some of the use cases can use both mAR and HMDs, while others rely on the use of HMDs. The latter can be used hands-free. However, HMDs are not yet sufficiently available for productive use (in either hardware or software applications). Therefore, the evaluation of these use cases depends heavily on the experts’ assessment of how quickly both hardware and software will be available, and how well they will function.

The first phase considered addresses the potential for AR in zoning. At this point, there are no detailed plans or constructed buildings; instead, the focus is on establishing future building masses. In UC 02 and UC 03, AR offers excellent value in communicating with nonexperts. Spatial problems (the arrangement of buildings in relation to each other and their heights) can be visualised with AR in an easily understandable way. Thus, AR enables the comparison of, e.g., different designs for an urban development area. In contrast, UC 01 starts one step earlier with the development of designs. Many different stakeholders (experts and nonexperts) can be involved in this process. For the collaborative creation of designs, advantages are seen with the use of haptic tools (e.g., building blocks) compared with the use of AR. These applications would be a step forward in citizens’ participation. Although AR is tested in individual research projects for participation [50], the content was mostly limited to the design of public spaces with trees or similar objects. All UCs in the zoning phase were based on mAR solutions and were, therefore, classified as directly implementable.

In the planning phase, the potential of AR as an additional quality assurance tool for surveyors was considered. The surveying plan was given high priority as it is the basis for both planning and plan checking (creation of the REM). With AR, both the survey results and the generated REM could be overlaid with the real environment on-site, creating a two-step quality assurance tool. This use case requires the use of AR using HMDs and, additionally, data transfer between surveying equipment and HMDs. The benefits must, therefore, be set against the technically complex implementation. Experts in the survey estimated that this implementation would take even longer, and less value would be added to their current workflow.

Table 2. Evaluation of the use cases in this paper concerning their benefits for the respective target groups and feasibility. The colours show the chosen benefit and feasibility.

	Use Case	Benefit for target group				Feasibility			
	Zoning								
UC 01	Cooperative planning workshops with AR	1	2	3	4	a	b	c	d
UC 02	AR in the context of information exhibitions	1	2	3	4	a	b	c	d
UC 03	AR as a visual support for decision-makers	1	2	3	4	a	b	c	d
	Planning								
UC 04	AR-supported surveying	1	2	3	4	a	b	c	d
	Permission								
UC 05	Digitisation of plan checking and hearing at the authority's office using AR	1	2	3	4	a	b	c	d
UC 06	AR plan checking for citizens on-site	1	2	3	4	a	b	c	d
UC 07	Checking the cityscape with AR	1	2	3	4	a	b	c	d
	Construction								
UC 08	AR as support for the building authority agents on-site	1	2	3	4	a	b	c	d
	Operation								
UC 09	Digital building books and AR	1	2	3	4	a	b	c	d
UC 10	AR in facility management	1	2	3	4	a	b	c	d
UC 11	AR-assisted firefighting operations	1	2	3	4	a	b	c	d
UC 12	Use of AR as part of the assessment of the building stock	1	2	3	4	a	b	c	d
		1 … very helpful 2 … helpful 3 … no influence 4 … obstructive				a … directly implementable b … implementable within 1–5 years c … implementable within 5–10 years d … implementable within 10+ years			

In Vienna, 13,000 building applications are submitted annually. This leads to a long processing time, making the permission phase one of the most time-consuming phases in connection with construction. The possibility of plan checking by neighbours in the permission process in Vienna requires good communication with nonexperts. AR as a visualisation tool offers significant advantages in this respect compared with plan-based communication (UC 05 and UC 06). An AR-based plan check at the authority level (UC 05) can be implemented directly due to the lack of reference to existing buildings. The technical basis and functionality are similar to existing AR apps (e.g., IKEA or DOKA uses) and, therefore, are directly implementable. A corresponding app was implemented and tested in the BRISE-Vienna research project. Both building agents and citizens see great benefits in using AR. The aforementioned assumptions (reducing process time by improving communication) will be evaluated in practical tests and the results will be published in the near future. Some research projects already show possibilities for on-site AR applications [17,21,51]. On-site plan checking is more technically complex to implement due to the need for visualisation in the context of the existing building stock on-site, and is therefore classified as "implementable within 1–5 years". The challenge is to locate the digital content and track it during movement. Currently, inaccuracies in the positioning of digital content (drift) hinder the spread of these apps. However, AR can assist not only nonexperts but also employees of the building authority when checking the cityscape (UV 07). The benefit was rated as "no influence" because there are other options (e.g., using a digital city map or VR) that do not require travel to the site but can be carried out from the office. The feasibility was rated b–c, as the use of both mAR and HMDs is possible.

AR originally serves as an extension of reality through virtual elements. In the construction phase, the approved objects are being built (are now real) and, thus, offer great potential for AR application possibilities. Buildings authority agents randomly check the consensus of the constructed building with the planning documents on-site (UC 08). The use of AR using HMDs can significantly reduce the familiarisation effect in projects and, thus, offers excellent benefits. However, this is linked to the use of HMDs and is, therefore, only to be expected in the medium term. mAR could be used immediately ("directly implementable"). However, the building authority agents saw much greater benefits in using HMDs. This led to the rating given in the table.

In the operation phase, there are several potentials for AR. One problem is the availability of data. With regard to the transfer of data to the digital building book (UC 09) or the FM (UC 10), AR represents a possibility, but this process can also be carried out without AR by scanning QR codes or RFIDs. The methods described in the use cases are based on the use of HMDs. Thus, implementation is not expected until the medium term. In addition, another potential for AR is seen in the area of firefighting. In the US, AR-assisted systems are already being tested to support firefighters (UC 11) [49]. In this context, AR is used for orientation in the case of heavy smoke development by highlighting the edges of rooms. An even greater added value can be realised through combination with BIM models. From these, e.g., additional information on the potential whereabouts of persons, and the statics of the fire behaviour of building component surfaces, could be extracted. After a fire, AR can significantly assist building authority agents in assessing the risk of building collapse by superimposing the load-bearing components (UC 12). Both UCs are based on the use of HMDs and, therefore, cannot be directly implemented.

5. Conclusions

The topic of augmented reality has already been taken up by many companies in the construction industry [11]. The possible applications of augmented reality (AR) by public authorities vary between different cities and countries due to their various legal frameworks. This paper, therefore, focuses on Austria and the City of Vienna. Nevertheless, many of the use cases described here can be transferred to other cities. Process analyses were conducted in cooperation with the Vienna Building Authority and stakeholder interviews with various participants to evaluate the potential in the public sphere. Due to lockdowns during the COVID-19 pandemic, the number of interviews was limited to a small group. In this analysis, a total of 21 AR use cases were identified, and 12 of them were examined in more detail. In addition to the classic phases of planning, construction, and operation, the use cases also deal with the officially relevant phases of zoning and permission. Research into AR in the construction industry is currently aimed at construction management and quality control, as well as collaboration and design support. The operational use of AR in Austria is limited to pilot projects. The lack of implementation of the BIM methodology in the heterogeneous office landscape in Austria, with many small and medium-sized offices that often shy away from software conversion and the associated costs, is slowing down digitisation [52]. Augmented reality and BIM enable an entirely new way of presenting planning information. Combining the two technologies allows for a more understandable representation of the content for people outside the field. Most use cases, therefore, require the existence of a BIM model. A prerequisite is that the authority has access to such a model. This is guaranteed by an openBIM permission procedure [8]. The planners submit a BIM model for a building permit. This means that the model is already available for AR use cases. The separate creation of such a model, just for AR use cases, would not be practicable due to the high effort required from the planner.

Plans are a suitable means of communication between knowledgeable persons. However, as an interface to the public, the authority is confronted with the problem that plans are not ideal as a universal language. The use of AR as a visualisation tool has already had a positive impact on spatial understanding, and thus on learning outcomes, in some studies [53]. This effect should also support the communication of the authority to the outside. This publication deals with fundamental research on using different AR use cases at the process level. Potentials were identified for both the internal activities of the authority (e.g., an inspection of the cityscape and support of the building authority agents) and external communication (e.g., participation in zoning and inspections). HMDs are a prerequisite for the feasibility of some use cases (e.g., support of the building authority's agents/the fire brigade). HMDs are characterised by two essential points compared with mAR: increased immersion and the "freeing" of the hands. In areas with increased hazard potential, such as construction sites or fire brigade operations, a large field of vision and the unrestricted availability of both hands are essential requirements. However, accuracies in positioning do not yet allow for use outside of research purposes. The development of these on-site use cases is linked to progress in hardware development.

This directly leads to the need for further research. Some interesting AR use cases require the use of AR glasses as hardware. In this case, the science is dependent on the progress of manufacturers. Tests have shown that further developments in the field of vision, robustness against natural influences, and localization accuracy are required. The largest possible field of view is essential from the perspective of occupational safety on construction sites. The field of view of current hardware is approx. 1/5 that of the human eye (e.g., 43.3° horizontal and 28.8° vertical with a Microsoft HoloLens2). The restriction of the peripheral field of vision due to thick spectacle frames also poses a danger on construction sites. Another problem is use in extreme light situations. In the construction industry, use conditions range from blazing sun to intense darkness. The currently frequently used infrared sensors for environmental detection are strongly affected by the sun's UV radiation, which means that their outdoor use is currently only possible to a limited extent. Furthermore, there is the problem of "noise" in very dark situations (e.g., cellars or tunnels). Widespread use in the construction industry requires improvements in this technology. The problems with the accuracy of overlaying digital and real-world content were previously addressed in this paper.

Further research is also needed on accessibility for all groups of people. Although AR is a good visualization option for tech-savvy individuals, this technology is also challenging for some citizens (e.g., older people). Moreover, some use cases are not barrier-free due to the use of mAR and thus represent a hurdle for use in public services. In summary, the benefits and challenges of AR in terms of usability need to be further explored.

The implementation and evaluation of individual-specific use cases are the subjects of current research activities within the framework of the BRISE-Vienna research project. As a first step, inspections by authorities and building negotiations are being digitised using AR.

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